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RADIO ENGINEERING SERIES

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Space Charge Waves in Electron Streams

A survey

by V.N.Shevchik and G.N.Shvedov

1. Introduction

One of the tendencies in the modern development of super-high frequency electronics is utilization of the principle of amplification and generation of electromagnetic oscillations through excitation of space charge waves in electron streams. Besides, implied under space charge waves is wave-like propagation of disturbances of density, current, field strength and velocity in the electron beam, the propagation velocity of these distubances depending on the space charge density in the stream.

An important foundation for developing electronic wave ideas in super-high frequency electronics was laid

by the works of Hahn and Ramo [1,2] who introduced the conception of space charge waves, based on the fact that plasma oscillations of electrons in a travelling stream can be described mathematically in the form of a wave.

In the general case many various types of space charge waves can exist in the electron stream; whereupon for some of them the laws of variation of radial and angular amplitude components are fairly complex. Two waves, however, one of which travels faster than electrons, the other slower than electrons, play the chief role. The interference between these two waves is analogous to a longitudinal standing wave in an elastic bar which is travelling with a certain velocity relative to an unmoving observer. Along the electron beam occurs periodic rotation of areas in which there is strong modulation of electron velocity and modulation of density is absent, with areas in which there is strong density modulation and velocity modulation is absent. This standing wave of variable velocity or density components is characterized by a long wave depending on voltage, current density and the geometry of the electron beam and conductors surrounding it, and is called a plasma long wave.

The importance of the works of Hahn and Ramo was

not understood for a long time. Understanding was to some extent hampered by the intensive development of the kinematic approach to analysis of the electronics of super-high frequency devices, an approach attractive for its pictorial nature, based on study of the travel of electrons, disregarding their natural interaction. The significance of these works has become fully apparent only in the last decade when it was demonstrated that the amplitude of space charge waves can under certain conditions be increased with distance.

Development of the electronic wave theory led to the emergence of ideas, new in principle, about the behaviour of electron streams at super-high frequencies and to the development of new electronic devices, the working principles of which are based on the use of oscillating phenomena in the electron beams themselves, which bring about amplification of space charge waves, and are not connected with the use of any kind of "material" oscillating systems.

The theory of space charge waves has at present been broadly elaborated and has proved very fruitful. It affords the possibility not only of explaining a number of experimental facts heretofore not understood, but also to forecast new possibilities in the utilization of

electron streams for amplification and generation of super-high frequency oscillations, lowering of the noise level in super-high frequency devices and so forth. The numerous available works devoted to space charge waves in electron beams have not, however, to the present time been systematized in sufficient degree. In this article an attempt is made to fill in this gap, if only to some extent. Given in it is a systèmatic examination of electronic wave processes in various electron streams. At the same time the authors deemed it expedient to dwell only on such circuits in which the electronic wave phenomena play the paramount role. For this reason systems like the travelling and revertive wave tubes are not examined; in them the electronic waves play merely the role of correction to the main electromagnetic events taking place in external oscillation circuits.

In the analysis the following system of equations was used.

1. Maxwell Equations. In calculating the vector fields in the surrounding streams of a waveguide system, the generalized wave equation is solved

$$\Delta \vec{E} - \varepsilon_0 \mu_0 \frac{\partial^2 \vec{E}}{\partial t^2} = \mu_0 \frac{\partial \vec{i}}{\partial t} + \frac{\nabla \rho}{\varepsilon_0}, \qquad (I.1)$$

or the Maxwell equations written through the scalar potential Φ and the magnetic vector potential $\vec{A}$. Joined

to it is the continuity equation

$$div\,\vec{i} = -\frac{\partial \rho}{\partial t}. \qquad (I.2)$$

If only the potential fields connected with the Coulomb interaction of electrons are taken into account, the equations for potential fields [3] are solved jointly with the continuity equation, for example:

$$\varepsilon_0 \frac{\partial \vec{E}}{\partial t} + \vec{i} = 0; \qquad (I.3)$$

$$div\,\vec{i} = -\frac{\partial \rho}{\partial t}. \qquad (I.3')$$

The solution of the field equations must satisfy the conditions of the continuity of tangential components $\vec{E}$ and $\vec{H}$ on the surface of the beam and surrounding conductor.

2. <u>Equation of movement</u> (in Euler variables) [4]:

$$e(\vec{E} + \vec{v} \times \vec{H}) = \frac{\partial \vec{v}}{\partial t} + (\vec{v}\nabla)\,\vec{v}. \qquad (I.4)$$

In case it is necessary to take into account the scattering of electrons in velocities, the kinetic equation for the function of electron distribution is used instead of (I.4).

All of the equations enumerated do not take into account the collisions of electrons, which are quite

admissible in the majority of cases in the super-high frequency band [3].

3. Equation for convection current.

$$i_0 + \tilde{i} = (\rho_0 + \tilde{\rho})(v_0 + \tilde{v}), \qquad (I.5)$$

in which i_0, ρ_0, v_0 are the constant components of current density, charge density and velocity, and $\tilde{i}, \tilde{\rho}, \tilde{v}$ are their variable components (ρ_0 for electrons is negative).

II Space Charge Waves of Constant Amplitude

In this section will be examined space charge waves in various electron streams which have in common the characteristic that the space charge waves being propagated in them do not change their amplitude with distance.

1. The infinitely extensive (one-dimensional) stream

In the one-dimensional stream of infinite length ρ_0 and v_0 do not depend on coordinates and time; the variable magnitudes are changed only in the direction of the axis Z. Constant electrical fields are absent in the circuit examined; the variable electrical field $\tilde{E}$ is directed along axis Z.

The analysis of this and all subsequent sections is based on the small signal assumption (we disregard terms with product of variable values).

Taking into account the indicated assumptions, equations (I.4),(I.2) and (I.5) assume the form:

$$\frac{\partial \tilde{v}}{\partial t} + v_0 \frac{\partial \tilde{v}}{\partial z} = \frac{e}{m}\tilde{E}; \quad \text{(II.1)}$$

$$\frac{\partial \tilde{i}}{\partial z} = -\frac{\partial \tilde{\rho}}{\partial t}; \quad \text{(II.2)}$$

$$\tilde{i} = \tilde{\rho} v_0 + \rho_0 \tilde{v}. \quad \text{(II.3)}$$

Excluding from equations (II.1),(II.2), (II.3) $\tilde{\rho}$ and $\tilde{v}$, a linear differential equation can be derived in partial derivatives connecting $\tilde{i}$ and $\tilde{E}$:

$$\frac{\partial^2 \tilde{i}}{\partial t^2} + 2v_0 \frac{\partial^2 \tilde{i}}{\partial z\,\partial t} + v_0^2 \frac{\partial^2 \tilde{i}}{\partial z^2} = \frac{e}{m}\rho_0 \cdot \frac{\partial \tilde{E}}{\partial t}. \quad \text{(II.4)}$$

Since field $\tilde{E}$ is created by variable charges in the electron stream itself, the full current law (I.3) can be used as a second equation connecting $\tilde{i}$ and $\tilde{E}$. Substituting it in (II.4), we derive

$$\frac{\partial^2 \tilde{i}}{\partial t^2} + 2v_0 \frac{\partial^2 \tilde{i}}{\partial z\,\partial t} + v_0^2 \frac{\partial^2 \tilde{i}}{\partial z^2} + \frac{e\rho_0}{m\varepsilon_0}\tilde{i} = 0. \quad \text{(II.5)}$$

The partial solution of the derived linear differential equation in partial derivatives with constant coefficients can be written in the form

$$\tilde{i} = Ae^{j(\omega t - \Gamma z)}. \quad \text{(II.6)}$$

The assumption that the variable values have the form (II.6) in which A in the general case depends on the transverse coordinates, will be widely used subsequently. This assumption is just for the following conditions: (1) constant parameters of beam (density, velocity, beam section) and surrounding system (diameter of drift tube and so forth) do not depend on coordinates z, although they can be functions of transverse coordinates; (2) the signal amplitude is sufficiently small that terms containing squares of variable values might be disregarded; (3) the electron beam does not have velocity distribution [4,5].

The substitution of (II.6) in (II.5) leads to the dispersion equation, the solution of which gives two values for Γ:

$$\Gamma_{1,2} = \frac{\omega}{v_0} \pm \frac{\omega_p}{v_0} = \beta \pm \beta_p, \qquad \text{(II.7)}$$

in which $\omega_p = \sqrt{\frac{e\rho_0}{m\varepsilon_0}}$ is plasma frequency.

Taking into account (II.7), (II.6), (II.1 – II.3), an expression can readily be derived for all variable values:

$$\tilde{i} = A_1 e^{j[\omega t - (\beta+\beta_p)z]} + A_2 e^{j[\omega t - (\beta-\beta_p)z]}; \qquad \text{(II.8)}$$

$$\tilde{\rho} = \frac{\beta+\beta_p}{\omega} A_1 e^{j[\omega t - (\beta+\beta_p)z]} + \frac{\beta-\beta_p}{\omega} A_2 e^{j[\omega t - (\beta-\beta_p)z]}; \qquad \text{(II.9)}$$

$$\tilde{v} = \frac{\omega_p}{\omega \rho_0} \left(-A_1 e^{j[\omega t - (\beta + \beta_p) z]} + A_2 e^{j[\omega t - (\beta - \beta_p) z]}\right); \quad \text{(II.10)}$$

$$\tilde{E} = j \frac{1}{\omega \varepsilon_0} \left(A_1 e^{j[\omega t - (\beta + \beta_p) z]} + A_2 e^{j[\omega t - (\beta - \beta_p) z]}\right). \quad \text{(II.11)}$$

According to (II.8) — (II.11) each variable value $\tilde{i}, \tilde{\rho}, \tilde{v}, \tilde{E}$ is described by two waves with phase velocities

$$v_{\phi 1,2} = \frac{v_0}{1 \pm \frac{\omega_p}{\omega}}. \quad \text{(II.12)}$$

The wave corresponding to the plus sign has $v_\phi < v_0$ and is called the slow wave of the space charge, and with the minus sign is the fast wave of the space charge.

The factors A_1 and A_2 are determined from boundary conditions. Let us assume that in the plane $z = 0$ are situated two infinitely close beam-intensity electrodes between which high frequency voltage is applied. At the output of this system the electron stream will be modulated in velocity. If t_1 = the modulator transit time, then the variable component of the velocity of electrons at the modulator output has the form $\tilde{v} = 2 v_1 e^{j\omega t_1}$. With $z = 0$ and $t = t_1$, the variable current $\tilde{i}$ is equal to zero [6]. Determining A_1 and A_2 from these conditions and substituting the result in (II.8) — (II.11), we derive:

$$\tilde{i} = -\frac{\omega \rho_0 v_1}{\omega_p} e^{j[\omega t - (\beta+\beta_p)z]} + \frac{\omega \rho_0 v_1}{\omega_p} e^{j[\omega t - (\beta-\beta_p)z]}; \quad (II.13)$$

$$\tilde{\rho} = -(\beta+\beta_p)\frac{\rho_0 v_1}{\omega_p} e^{j[\omega t - (\beta+\beta_p)z]} + (\beta-\beta_p)\frac{\rho_0 v_1}{\omega_p} \times$$

$$\times e^{j[\omega t - (\beta-\beta_p)z]}; \quad (II.14)$$

$$\tilde{v} = v_1 e^{j[\omega t - (\beta+\beta_p)z]} + v_1 e^{j[\omega t - (\beta-\beta_p)z]}; \quad (II.15)$$

$$\tilde{E} = -j\frac{v_1 \rho_0}{\varepsilon_0 \omega_p} e^{j[\omega t - (\beta+\beta_p)z]} + j\frac{v_1 \rho_0}{\varepsilon_0 \omega_p} e^{j[\omega t - (\beta-\beta_p)z]}. \quad (II.16)$$

The first terms here refer to the slow wave, and the second to the fast. We will analyse the behaviour of the velocity and current waves. From (II.15), it is evident that the two waves of velocity begin their travel in phase. In the initial plane $z = 0$ therefore, the amplitude of the variable velocity component is equal to the sum of the wave amplitudes. But since the two waves differ in velocity of propagation, it should be expected that the phase difference accumulating in proportion to travel will at some point amount to 180^0, and the waves are mutually cancelled. After the passage of another such segment the waves are again composed in phase and give the maximum amplitude etc. Along the beam a standing wave of variable velocity component is thus formed. The current variation along the beam is analogous, but inasmuch as the current waves begin their travel in phase opposition (-

(II.13), the standing wave of current is shifted in space with respect to the standing wave of velocity by a quarter length of the plasma wave $\frac{\lambda}{4} = \frac{\pi V_0}{2\omega_p}$. The periodicity of antinodes (or nodes) of the standing waves of current and velocity amounts to $\frac{\lambda_p}{2}$. The dependence of $\tilde{i}$ and $\tilde{v}$ on z in the fixated moment of time is given in Fig. 1.

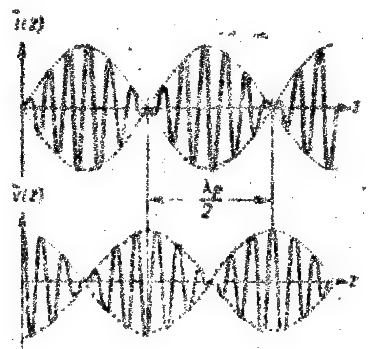

Fig. 1

At each point the velocity and current vary harmonically with the phase shift $\frac{\pi}{2}$, whereupon the amplitude of oscillations depends on z. The origin of such a picture becomes graphic, if electron travel beyond the modulator, taking into account the forces of charge repulsion, be represented in coordinates z, t (Fig.2). On escape from the modulator, the electrons have different velocities (varied slope of travel curves); the variable current is equal to zero. In proportion to travel, condensations

and rarefactions are formed on account of the difference in velocities and the overtaking of some electrons by others, alternating current arises. At the same time the space charge forces arising in the electron condensations retard the fast electrons and accelerate the slow electrons, which had emerged from the modulator earlier and therefore proved to be ahead. In this way the denser the clusters (the greater the alternating current amplitude), the more the velocities of the electrons are equalized (the less the amplitude of the variable component of velocity). At the point of maximal density the velocities of all electrons are equal, and the amplitude of the variable component of velocity is equal to zero (compare Fig. 1 and 2). Further the cluster of electrons

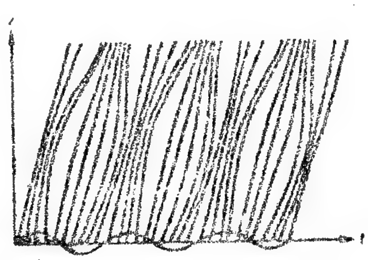

Fig. 2

begins "to fall apart": the electrons of the cluster's forward part are accelerated while the electrons going behind are retarded. The velocities of the electrons become increasingly different, while the beam density is

equalized. The difference in velocities which had appeared under the action of space charge forces again brings about the formation of condensation and so forth. At the same time the kinetic energy corresponding to the variable component of electron velocity is converted to the potential energy of electron condensations and vice versa.

Definite power flows [5,7,8,9,10] are ascribed to the slow and fast waves of the space charge, since the kinetic energy of electrons in the stream modulated by one or the other wave, differs from the kinetic energy of electrons in the undisturbed beam. The variation of the kinetic energy of electrons at a distance of one space charge wave length can be expressed so:

$$\Delta W_k = \int_0^\lambda dW_k - W_{k0} = \int_0^{\frac{2\pi}{\beta \pm \beta_p}} \frac{m(v_0 + \tilde{v})^2}{2} \times$$

$$\times \frac{(\rho_0 + \tilde{\rho})}{e} dz - \frac{m v_0^2}{2} \frac{\rho_0}{e} \frac{2\pi}{\beta \pm \beta_p}. \tag{II.17}$$

In calculating ΔW_k for the fast wave or for the slow wave, the pertinent sign with β_p should be chosen in (II.17) and instead of $\tilde{v}$ and $\tilde{\rho}$ the pertinent terms from (II.15) and (II.14) should be substituted in (II.17). Computation shows that with conditions usually observed $\frac{\omega_p}{\omega} \ll 1$ ΔW_k

is found negative for the slow wave and positive for the fast wave. It is therefore assumed that the space charge slow wave carries the negative power flow while the fast wave carries the positive. Physically this means that with modulation of the slow wave flow a greater number of electrons is found in places with lesser total velocity and a lesser number of electrons is in places with greater total velocity. In the fast wave the grouping of electrons occurs in the reverse order.

2. Stream of Plasma

An aggregate of positive and negative charges such that its total charge is equal to zero, is called plasma. Applied to the electron beam this means that the positive ions present in it compensate the space charge of electons.

The assumption about the plasma state of the electron beam is widely employed in the literature, since it permits assuming that also in a stream of finite section v_0 and ρ_0 are constant and identical at all points of the beam, i.e. not to take into account the "sagging" of potential in the stream section on account of the space charge of the electrons. Moreover, examination of the oscillation phenomena in plasma makes possible a graphic

picture of the nature of the two space charge waves.

Let us examine plasma at rest with uniform distribution of layers of electrons and positive ions (Fig.3).

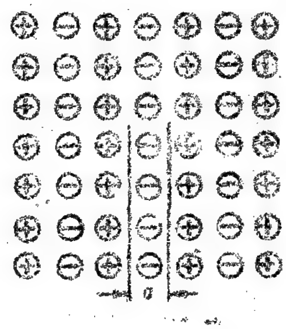

Fig.3

Assume that a disturbance arose in the plasma of a kind such that electron layer a was shifted to the right. At the same time resilient forces from the side of the slightly mobile positive ions begin to act on layer a and being then left to itself, layer a makes an oscillatory movement near the position of equilibrium. These oscillations are transmitted to the next layers of electrons connected with layer a by Coulomb forces. In the plasma to both sides will be propogated rarefaction and condensation in the form of two waves of density running in opposite directions. Such oscillations have been investigated experimentally: they are characterized by the natural frequency of plasma $\omega_p = \sqrt{\frac{e\rho_0}{m\varepsilon_0}}$ [11].

If then an electron stream be imagined that is

moving with a velocity much greater than the velocity of the propagation of the density wave in the plasma, we derive the already familiar two waves of the space charge one of which is moving somewhat slower and the other somewhat faster than the electrons. The original disturbance of the a layer of electrons can be explained by the action of the modulator field.

The assumption of the plasma state of the electron stream makes it possible to analyse the space charge waves in an electron stream of finite section, in particular, in the most frequently encountered cylindrical stream.

The problem is usually solved with the following initial assumptions: v_0 and ρ_0 are constant at all points of the beam; the beam does not have velocity distribution; the amplitude of signals is considered small; the beam is focused by an infinitely strong longitudinal magnetic field (the finite magnetic field is examined below).

The system of equations (I.1), (I.4), (I.5) can be solved after making substitution (II.6) somewhat more complex and substituting variable values in the form [1,12, 4]

$$\tilde{a} = A_0 J_0 (Tr) e^{j(\omega t - \Gamma z)}. \qquad (II.18)$$

The writing of Maxwell's equations through potential functions and solving them with reference to potentials,

can also be used. The second approach will be used below [2,13].

The solution is developed in a cylindrical system of coordinates, in the assumption of circular symmetry $\left(\frac{\partial}{\partial\varphi} = 0\right)$. The variable values $\tilde{\rho}$, v and the variable scalar potential Φ are represented in the form:

$$\tilde{\rho} = \rho_0 + \rho_1 e^{j(\omega t - \Gamma z)};$$

$$\tilde{v} = v_0 + v_z e^{j(\omega t - \Gamma z)};$$

$$\Phi = \Phi_1 e^{j(\omega t - \Gamma z)},$$

in which Φ_1, ρ_1, v_z are functions only of r; disturbances are assumed to be small: $\rho_1 \ll \rho_0$, $v_z \ll v_0$.

By means of joint solution of heterogeneous wave equation for Φ

$$\left(\nabla^2 - \varepsilon_0\mu_0 \frac{\partial^2}{\partial t^2}\right)\Phi = -\frac{\tilde{\rho}}{\varepsilon_0} \qquad \text{(II.19)}$$

and equations (II.2) and (I.4) taking into account the assumptions introduced the equation for Φ_1 can be reached:

$$\frac{\partial^2 \Phi_1}{\partial r^2} + \frac{1}{r}\frac{\partial \Phi_1}{\partial r} + \left[\left(\frac{\omega_p^2}{\omega_s^2} - 1\right)\left(\Gamma^2 - k^2\right)\right]\Phi_1 = 0. \qquad \text{(II.20)}$$

Here $\omega_s = \omega - \Gamma v_0$; $k^2 = \varepsilon_0\mu_0\omega^2$. Solution (II.20) for

the area inside the beam has the form:

$$\Phi_1 = B J_0(T r), \tag{II.21}$$

in which

$$T = \sqrt{\left(\frac{\omega_p^2}{\omega_1^2} - 1\right)\left(\Gamma^2 - k^2\right)}, \tag{II.22}$$

while the solution for the space between the beam and the conducting cylinder

$$\Phi_2 = C\,[I_0(\tau r) + D K_0(\tau r)], \tag{II.22'}$$

in which I_0 and K_0 are modified Bessel functions and

$$\tau = \sqrt{\Gamma^2 - k^2}. \tag{II.23}$$

From the boundary conditions on the surface of the beam ($r = b$) and the conducting cylinder ($r = a$) are determined the values D and $\frac{C}{B}$ and the dispersion equation is found for constant propagation Γ:

$$-(T b)\frac{J_1(T b)}{J_0(T b)} = (\tau b)\frac{I_1(\tau b) - D K_1(\tau b)}{I_0(\tau b) + D K_0(\tau b)}. \tag{II.24}$$

The transcendent equation (II.24) is solved graphically: it determines the infinite series of values T, which are its roots. On the basis of the results of the preceding chapter, it should be expected that $\Gamma \approx \Gamma_0 = \frac{\omega}{v_0}$ and consequently, $\Gamma^2 \gg k^2$ (at the same time only space

charge waves are taken into consideration and the electromagnetic field waves in the surrounding system are not examined). Then from (II.22) we find

$$\Gamma = \frac{\omega}{v_0} \pm \frac{\omega_p}{v_0} \frac{1}{\sqrt{1+\frac{T^2 v_0^2}{\omega^2}}} \qquad \text{(II.25)}$$

The value $\frac{1}{\sqrt{1+\frac{T^2 v_0^2}{\omega^2}}}$ is usually considerably less than unity; at the same time T takes an infinite series of values.

So, in distinction from an infinitely extensive beam (II.7), we have derived an infinite sequence of Γ values. Thus, an infinite number of pairs of space charge waves arise in the examined case. The emergence of an infinite series of waves is explained by the imposition of a boundary condition (the conversion of the tangential electrical field on the conducting cylinder surface to zero). The waves which satisfy this condition can have radius distribution with any possible number of zeros and form an infinite series. Shown in Fig. 4 is the spectrum of Γ values for these waves [14]. In the upper part of the drawing two values of Γ are plotted for the infinitely extensive beam. In the middle part of the drawing is shown the Γ spectrum derived from (II.24). Here

Γ_{01} and Γ_{02} correspond to the least T, i.e. to waves with a velocity that differs most from v_0. These waves of the lowest order represent the greatest interest because the field of these waves do not have zeros inside the beam cross section, and they are most readily excited by the high frequency field. The waves of the highest orders have 1,2,3,.. zeros in the beam cross section. Shown in Fig.5 is the distribution of fields in the radius of the beam for waves 1,2,3 and 4th order [15]. It is obvious that waves of the highest orders are poorly excited, since their field changes direction on the transition from one area of cross section to another. Still another characteristic of waves of the highest order [16] is the very low energy carried by them in comparison with the energy of lowest order waves. The next important distinction of waves of varied order is in the effective plasma frequency. In formula (II.15), the value $\frac{\omega_p}{\sqrt{1 + T^2 v_0^2/\omega^2}} = \omega_s$ can be considered a certain effective plasma frequency, taking into account finite dimensions of the stream. The effective frequency $\omega_s < \omega_p$ and is reduced with the growth of wave order. The spacing between nodes of current or velocity increases correspondingly.

The foregoing is justified for the case of the

infinitely strong focusing magnetic field. Such a condition is usually well fulfilled in practice [17]. In the case of the finite magnetic field [1,14,16,18], the results are modified as shown in the lower part of Fig. 4: still another group of wave pairs appears, "travelling" with reduction of the magnetic field to the values $\frac{\omega}{v_0} \pm \frac{\omega_p}{v_0}$; the already present values of Γ are displaced at the same time to $\Gamma_0 = \frac{\omega}{v_0}$. These results are justified for the conditions shown in [14].

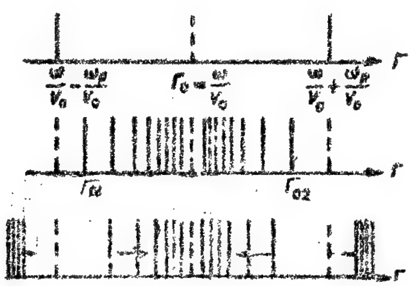

Fig.4.

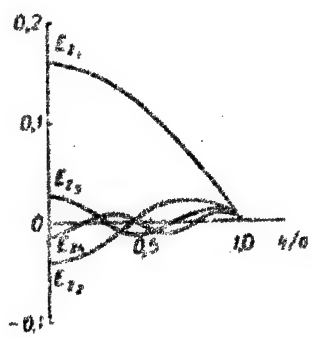

Fig. 5.

It should be noted also that if we do not confine ourselves to the case $\Gamma \approx \Gamma_0$ and take into account the waves of the field of the waveguide system's surrounding stream [1,16,18], then it is found that four waves correspond to each order: two space charge waves and two field waves. At frequencies higher than the waveguide system's critical frequency, these field waves are

weakly changed by the straight and revertive waves of this system. At frequencies below the waveguide system's critical frequency, however, two complex Γ values emerge, which correspond to the rising and damped waves of the field, travelling oppositely to the electron stream. In this case, however, as has been shown in [5, 18], it is not possible to utilize the rising wave for amplification.

It can thus be assumed that in restricted streams of plasma, space charge waves of constant amplitude are propagated like the waves in an infinitely extensive stream. If the equations (II.25) and (II.7) be written in the form

$$\Gamma = \frac{\omega}{v_0} \pm \frac{\omega_p S}{v_0}, \qquad \text{(II.26)}$$

then the difference between the two systems examined will be defined by the value of multiplier S. For the infinitely extensive beam $S = 1$. For the plasma stream of finite cross section $S < 1$ and assumes a series of values. The multiplier $S < 1$ emerges as a result of the reduction in space charge action caused by the imposition of boundary conditions. Actually, the conversion of the tangential electrical field on the drift tube surface to zero, reduces the space charge field in the beam in comparison to the field in the absence of the drift tube.

The introduction of multiplier S is a convenient way to calculate the finite dimensions of different streams [19].

In concluding this section, we shall dwell briefly on a number of other works. Wayes not axially symmetrical without fail (in distinction from [2]) are examined in [13]. The cases of the strong focusing magnetic field and the absence of magnetic field are examined.

The factor of reduction of plasma frequency for the beam with ring-shaped cross section is examined in [20]. It is found dependent in the first place on the ring width.

Equations are formulated in [21] for the field and electron in plasma at rest, then by means of the formulae of the relativity theory are converted to travelling plasma. Equations are evolved for $\widetilde{\psi}$ and $\widetilde{i}$, analogous to (II.10) and (II.8), but with relativistic correction for λ_p

$$\lambda_p = 2\pi \frac{v_0}{\omega_p \sqrt{1 - v_0^2/c^2}}.$$

3. Stream of Brillouin

The stream of Brillouin [22,23,24] is formed

by electrons emitted by a cathode situated outside the magnetic field and afterward entering into a homogeneous magnetic field of definite magnitude parallel to the system axis. One of this stream's most important characteristics is the constancy of v_{0z} and ρ_0 in the stream volume, which greatly eases the analysis of space charge waves in this circuit.

Let us dwell briefly on the question of the formation of the Brillouin stream and its characteristics (Fig.6). Pole terminal 1 screens cathode 2 from magnetic field H. Before entering the longitudinal magnetic field,

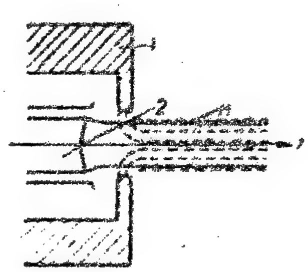

Fig. 6

the electron stream passes the area of radial magnetic field in the pole terminal opening. At the same time the electrons acquire rotary motion with an angular velocity depending on the magnetic field magnitude

$$\dot{\varphi} = -\frac{1}{2}\frac{e}{m}B_z. \qquad \text{(II.27)}$$

Since the angular velocity is identical for all electrons, the stream rotates as a single whole. With further travel in the longitudinal magnetic field, forces act on the electrons only in the radial direction, as in the absence of electrical fields, the electrons drift along axis Z. The following radial forces act upon the electrons: centrifugal force and force of the space charge directed in a radius from the center, and the Lorentz force in the radius toward the center. If the radius of stream b, the current I, the magnetic induction B and the potential in the axis U satisfy the correlation

$$b^2 = \frac{\sqrt{2}\, I}{\pi \varepsilon_0 \left(\frac{e}{m}\right)^{3/2} B^2 U^{1/2}} \qquad \text{(II.28)}$$

and the electrons enter the longitudinal magnetic field parallel to the axis, then the equivalent radial forces are equal to zero, and the stream retains a constant radius during travel. The presence of rotary motion leads also to the progressive velocities of all electrons v_{oz} being equalized to the value $\sqrt{2 \frac{e}{m} U}$, the determined value of the potential in the stream axis. This is explained by the point that the gain in energy of the electrons on account of the increase of potential in the stream periphery goes out to energy of electron rotation,

inasmuch as the linear velocity of electrons rises with the enlargement of radius. At the same time the velocity in the axis v_{0z} remains invariable and equal to the velocity of electrons in the stream axis.

In the analysis of space charge waves in the Brillouin stream, the following assumptions are introduced: the density ρ_0 and velocity v_0 are constant at all points of the beam, the beam cross section remains constant; the stream electrons rotate around axis z with an angular velocity determined by the correlation (II.27). The stream travels inside a cylindrical drift tube in a longitudinal magnetic field which satisfies the condition (II.28). The stream is infinitely long, no changes occur of any kind in azimuth. Periodic disturbance with frequency ω of small magnitude is propagated along the beam. The beam does not have velocity distribution; $\left(\frac{v_0}{c}\right)^2 \ll 1$, so that the magnetic field of the beam itself can be disregarded. With these assumptions the variable magnitudes can be written in the form:

$$\tilde{a}(r, \varphi, z, t) = A(r)\, e^{j(\omega t - \Gamma z)}. \qquad \text{(II.29)}$$

The examination is based on Maxwell's equations:

$$\operatorname{rot} \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{i}; \qquad \text{(II.30)}$$
$$\operatorname{rot} \vec{E} = -\frac{\partial \vec{B}}{\partial t}.$$

motion equation (I.4) and continuity equation (I.2). At the same time the following expressions are used for currents:

$$
\begin{aligned}
\tilde{i}_r &= \rho_0 \tilde{v}_r; \\
\tilde{i}_\varphi &= \rho_0 \tilde{v}_\varphi + \tilde{\rho} v_{\varphi_0}; \\
\tilde{i}_z &= \rho_0 \tilde{v}_z + \tilde{\rho} v_0 .
\end{aligned}
\qquad (II.31)
$$

The solution system is usual: from equations (II.31), (I.4) and (I.2) are excluded density and velocity, and the values $\tilde{i}_r$, $\tilde{i}_\varphi$ and $\tilde{i}_z$ are expressed through the electrical and magnetic fields. Then substituting $\tilde{i}_r$, $\tilde{i}_\varphi$, $\tilde{i}_z$ in (II.30), expressions are found for the components of the fields. The remaining variable values are expressed through known field components. Calculation of boundary conditions on the beam surface gives the dispersion equation for Γ, solution of which has the form:

$$\Gamma = \frac{\omega}{v_0} \pm \frac{\omega_p}{v_0} \sqrt{1 + \frac{\delta^2}{(pb)^2}} . \qquad (II.32)$$

Here δ is proportional to the magnetic field and is usually small (for $B_0 = 1000$ гс, $\delta^2 = 0.0215$), pb is the parameter, whereupon $(pb)^2 > 1$. Derived thus is a very narrow spectrum of values Γ, situated very close to the values Γ for the infinitely extensive beam (II.7).

In the analysis given a very essential moment is ommitted: the high frequency variations of the diameter

of Brillouin's stream. They arise because at points of densification and rarefication of electrons, equilibrium of Lorentz forces, the centrifugal and space charge is attained respectively with the larger and smaller beam diameter. In the presence of a periodically changing beam cross section, it is not possible to apply the substitution (II.29). In a number of works, an effort is made to avoid this difficutly by means of introducing an equivalent stream with a constant cross section [25,26,27,28]. According to [25] a hollow cylindrical tube of current with periodically varying diameter, cut out from the real stream of Brillouin, is substituted by a hollow cylinder of constant diameter of an equivalent stream under the condition of charge parity per unit of length of both cylinders. In addition to this, the variable density of the equivalent cylinder $\tilde{\rho}_1$ takes into account the variation of density in the real beam on account of electron grouping as well as beam cross section variation

$$\tilde{\rho}_1 = \tilde{\rho} + \rho_0 \frac{\widetilde{\Delta r}}{r} . \qquad \text{(II.33)}$$

Here $\tilde{\rho}$ is the variable density in the real stream;

ρ_0 is the constant density in the real beam; Δr is the variation of the real beam radius. This method allows for using the course of considerations [29], after

having substituted $\tilde{\rho}$ for $\tilde{\rho}_1$ in (II.31). In this case the solution [25] gives an expression for Γ that differs from (II.32). Along with the values Γ according to (II.32), for which $s \approx 1$, appear the values Γ for which $|s| < 1$, as was also the case in the plasma stream. Represented in Fig.7 [25] is the comparative course of factor of plasma frequency reduction $S = \frac{\omega_s}{\omega_p}$ depending on $\beta_0 b$ for the plasma stream and the stream of Brillouin (at the same time it is assumed $\frac{b}{a} = 0$).

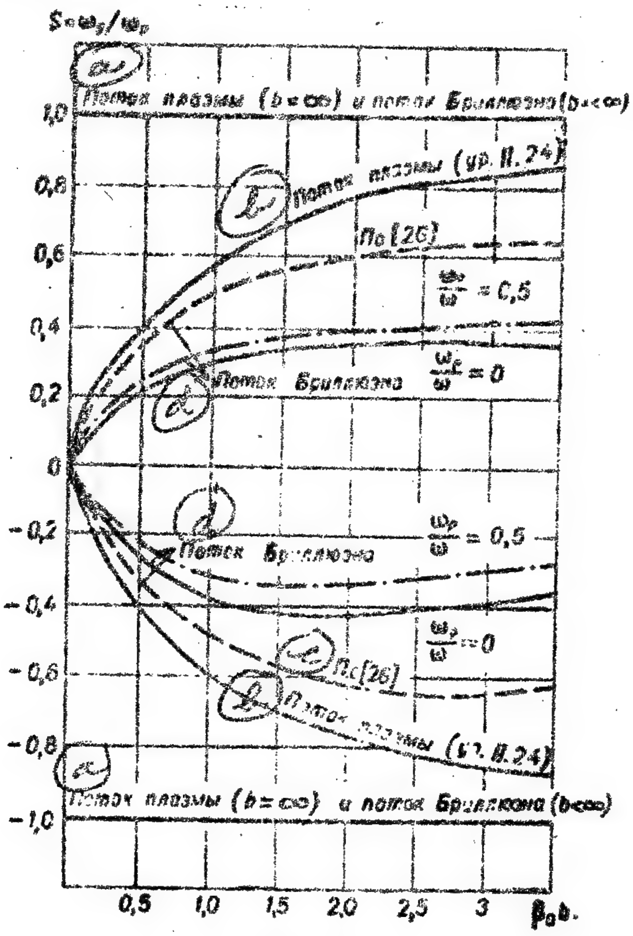

Fig.7

a- plasma stream ($b = \infty$) and stream of Brillouin ($b = < \infty$)

b- stream of plasma (equation (II.24)

c- according to (26)

d- stream of Brillouin

Here a is the radius of the conducting cylinder surrounding the stream.

It is expedient to present certain experimental facts that will make it possible to judge as to what kind of stream is encountered in real super-high-frequency electronic devices - the stream of plasma or the stream of Brillouin, and also as to what method of computing the high frequency variations of beam diameter reflects more closely the real situatinn - the method developed in [25] or the method developed in [26]. Experiment shows that amplification of the travelling wave tube is monotánically decreased if the intensity of the focusing magnetic field be increased, selecting all remaining parameters optimal. From the viewpoint of plasma theory, this effect is not explaihable, since it presupposes that the magnetic field is always sufficiently strong in order to secure straight line motion of electrons. But if it be presumed that in all magnetic field values the beam behaves as an ideal beam of Brillouin, then the growth of the magnetic field is felt in decrease of the beam diamter (II.28)

and consequently, in reduction of its connection with the spiral. Pertinent calculations [25] give a result that coincides well with the experiment. The coincidence of analogous results of the work [26] with the experiment is inferior.

Another experimental fact, the increase of current in the spiral with the increase of the input signal's amplitude, is also incomprehensible from the viewpoint of plasma theory, but finds a good explanation when cross motions of electrons are taken into account. It is indicated in [25] that the magnitude Δr is approximately proportional to the square root of the high frequency power, which explains well the increase of interception of electrons by the spiral.

The question as to what kind of stream, plasma or Brillouin, should be presumed in these or those definite conditions, has not been solved with finality at the present time. Some light is thrown on this question by measurement of the plasma wave length and subsequent comparison of experimental data with the theoretically derived values for the effective wave length $\lambda_s = \frac{2\pi V_0}{\omega_s}$ in the case of the plasma stream and the stream of Brillouin. Experiment [25,30] has shown that with impulse passage of the electron stream wave lengths λ_s are derived close to the values λ_s

for the stream of Brillouin according to the formulae of work [25]. In continuous conditions the values λ_s proved to be close to the values λ_s for the plasma stream according to [31]. Evidently, ionic compensation of the space charge of electrons is established in continuous conditions and fails to be established in impulse passage.

It should be observed as well that the design itself of electrodes and the distribution of potential on them have an effect on the degree of neutralization of the electron charge by ions. After creating a space, in the borders of which the potential is somewhat higher than it is inside, an ion trap [32-38] can be obtained which will make it possible, at a customary vacuum of the order of 10^{-6} mm of mercury column, to accumulate a quantity of ions sufficient for almost complete neutralization of the charge of electrons. It is therefore thought that there are more grounds to presume the presence of plasma in tubes with grids than in tubes without grids. The assumption of the plasma state of the electron stream is apparently well grounded also in tubes with gas focusing of the electron stream. In [39] an interesting remark is made about the role of positive ions in the electron beam. For maintenance of stream uniformity it is found necessary to secure $\frac{dv_0}{dz} = 0$ and ω_p = const, and together with other factors the density of ions must secure precisely these . .

conditions and not complete compensation of the electron charge.

In [40,41,42] were investigated waves of a space charge in an electron stream with cathode placed directly in the magnetic field (in distinction from the stream of - Brillouin). The method used in work [40] is the same as that of [26]. Articles [41] and [42] are based on [25] and [29]. It was found that in the case examined λ_s is shorter than for the stream of Brillouin. The λ_s shortening occurs on account of the reduction of beam diameter as well as on account of the plasma frequency reduction factor S depending on the magnetic field.

4. Stream with Bending Deflection of Potential On Account of Space Charge.

Let us examine the waves of a space charge in electron streams taking into account lowering of potential inside the stream on account of the cavity charge of electrons.

In connection with the change of potential in the beam cross section, the velocity of electrons at the stream borders will be greater than at the axis. The electron stream in this way becomes inhomogeneous.

The analysis of such a stream is of interest because incorrect views have been expressed on the possibility of

amplification of space charge waves in it, depending supposedly on the interaction of central and peripheral electrons. This opinion was expressed in work [43] and was grounded in an experiment with a single beam amplifier tube. Subsequently strictly set-up experiments showed the absence of amplification in a single beam system. It will be demonstrated below that in a stream with bending deflection of potential, only waves of constant amplitude can be propagated.

The analysis will be carried out on the assumption of smallness of signal, single-valued dependence of electron velocity on coordinates and dependence of variable values on coordinates and time in the form:

$$a = A_T e^{j(\omega t - \Gamma z)}. \qquad (II.34)$$

in which A_T is the function of cross coordinates. It is assumed in addition that the constant values ρ_0 and v_0 depend only on the cross coordinates and the velocity is directed only along z (the stream is limited by a strong magnetic field). With these assumptions, using equations (I.1),(I.2), (I.4), (I.5) and (II.34), the following equation can be derived for the lengthwise component of the electrical field:

$$\Delta_T E_z + \left(\frac{\omega^2}{c^2} - \Gamma^2\right)\left(1 - \frac{\omega^2_p}{(\omega - \Gamma v_0)^2}\right) E_z = 0. \quad \text{(II.35)}$$

Here Δ_T is the Laplacian operator for cross coordinates. The solution of equation (II.35) with homologous boundary conditions gives the unknown values Γ.

Let us examine a flat band stream moving along axis Z, infinite along axis y and limited in axis x by two conducting plates. According to [44] we assume ρ_0 is independent of x, while v_0 depends linearly on X. Then (II.35) can be written:

$$\frac{d^2 E_z}{dx^2} + \left(\frac{\omega^2}{c^2} - \Gamma^2\right)\left(1 - \frac{\omega_p^2}{\left[\omega - \Gamma\left(v_0(0) + \frac{dv_0}{dx}x\right)\right]^2}\right) E_z = 0. \quad \text{(II.36)}$$

For further simplification of equation (II.36), it is taken into account that for waves of the space charge $\frac{\omega^2}{c^2} \ll |\Gamma^2|$ and the transformation is introduced

$$u = \frac{\omega - \Gamma v_0}{\frac{dv_0}{dx}}. \quad \text{(II.37)}$$

Assume $\frac{dv_0}{dx} = \omega_p$(it will be indicated below how $\frac{dv_0}{dx} \neq \omega_p$ influences). Then the equation (II.36)

assumes the form:

$$\frac{d^2 E_z}{d u^2} - \left(1 - \frac{1}{u^2}\right) E_z = 0. \qquad \text{(II.38)}$$

We introduce boundary conditions and analyze if amplification of space charge waves in a beam is possible. Assume the stream is bounded by conducting plates at the points χ_A and χ_B. The velocity of electrons at these points will be respectively $v_0(\chi_A)$ and $v_0(\chi_B)$, whereupon $v_0(\chi_A) > v_0(\chi_B)$. The electrical field at points χ_A and χ_B is converted to zero.

For amplification it is essential that Γ be complex firstly, and secondly, according to [10] the phase velocity of the amplifying wave must satisfy the inequation $v_0(\chi_B) < v_\phi < v_0(\chi_A)$. Analysis [44] shows that the root of equation (II.38) does not satisfy the above-indicated conditions: two sequences of real values are derived for Γ. The phase velocities of one sequence of waves is greater than $v_0(\chi_A)$ while of the other it is less than $v_0(\chi_B)$. If $\frac{d v_0}{dx} \neq \omega_p$ be assumed, the values Γ are somewhat modified, but rising waves do not appear.

In [45] the band stream is examined on the assumption that

$$v_0(x) = v_0(0)\left(1 + \frac{1}{2}\sigma h_e^2 x^2\right) \text{ и } \rho_0(x) = \rho_0(0)\left(1 - \frac{1}{2}\sigma h_0^2 x^2\right),$$

in which σ characterizes the degree of compensation of

the electron volume charge by ions, and $h_0 = \frac{e\rho_0(0)}{m\varepsilon_0 v_0(0)} = \frac{\omega_p(0)}{v_0(0)}$. The analysis, more complex than in [44] and containing a series of approximations, leads to the same result - the absence of rising waves of the space charge.

Finally, in [44] a cylindrical stream is investigated with a density uniform in cross section and the velocity dependence on the radius in the form $v_0(r) \approx v_0(0) + \frac{\rho_0 e}{4 m\varepsilon_0 v_0(0)} r^2$. The equation for the cylindrical stream was solved on an electronic computer and the results also showed the absence of rising waves. Fig.8 drawn from computation results shows the displacement of values of phase velocities of space charge waves in a cylindrical beam with bending deflection of potential as compared to a single-velocity beam.

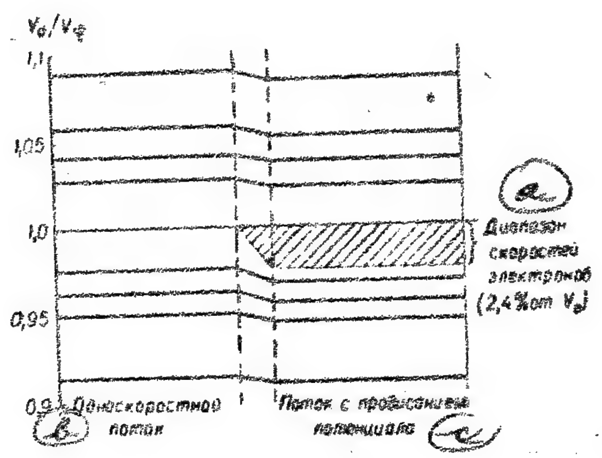

Fig 8

a - band of electron velocities (2.4 % of V_0)

b - single velocity stream

c - stream with bending deflection of potential

In summarizing, it should be stressed that space charge waves of constant amplitude only can be propagated in all the streams examined (sections II.1 to II.4). Further to be examined are electron beams in which under definite conditions space charge waves can arise that modify the amplitude with distance.

III. Space Charge Waves of Changing Amplitude

In electron streams, the homogeniety of which has been in a definite manner disturbed, space charge waves that change amplitude with distance can arise. It is expedient to begin the study of the conditions under which such waves appear with an analysis of an electron beam having velocity distribution.

1. Dispersion Equation for Electron Streams with Velocity Distribution

Let us assume that along with continuous velocity distribution $f(v)$ an infinitely extensive stream contains a certain quantity of elementary streams having discretely distributed velocities: $v_0 v$ (v = 1,...,m). If N_0 is the full number of electrons per unit of stream volume,

N_0 is the number of electrons in a unit of volume of an elementary stream with velocity v_0, then one can write:

$$N_0 = \sum_{\nu=1}^{m} N_{0\nu} + \int_{-\infty}^{+\infty} f_0(v_0)\,dv_0. \qquad \text{(III.1)}$$

We introduce the simplifying assumptions: (1) the charges in each elementary stream and each interval of velocities v_0, $v_0 + dv_0$ are distributed uniformly in the beam cross section; (2) the law of distribution (III.1) is one and the same for all cross sections, i.e. N_0, N_0 and $f_0(v_0)$ do not depend on z; (3) the variable magnitudes $\tilde{i}, \tilde{v}, \tilde{f}$ are sufficiently small that their products might be disregarded.

With modulation of electrons in velocity, the variable term $\tilde{f}(v_0)$ appears in the electron velocity distribution. Taking this into account, the variable component of charge density is written so:

$$\tilde{\rho} = e\sum \tilde{N}_\nu + e\int_{-\infty}^{\infty} \tilde{f}(v_0)\,dv_0. \qquad \text{(III.2)}$$

and the variable current density as follows:

$$\tilde{i} = e\sum (N_{0\nu}\tilde{v}_\nu + v_{0\nu}\tilde{N}_\nu) + e\int_{-\infty}^{\infty} [f_0(v_0)\,\tilde{v}(v_0) + v_0\tilde{f}(v_0)]\,dv_0. \qquad \text{(III.3)}$$

By virtue of assumptions 1 and 2, the continuity equation has force for each value v_0

$$j\omega\tilde{\rho} + \frac{\partial \tilde{i}}{\partial z} = 0. \qquad \text{(III.4)}$$

The exponential substitution (II.6) is approximately justified also in the analysis of a stream with velocity distribution [46].

Taking (II.6), (III.2) and (III.3) into account the equation (III.4) is written in the form:

$$\begin{aligned} \omega_s \tilde{f} &= \Gamma f_0 \tilde{v} \\ \text{и} \quad \omega_{sv} \tilde{N}_v &= \Gamma N_{0v} \tilde{v}_v , \end{aligned} \qquad \text{(III.5)}$$

in which $\omega_s = \omega - \Gamma v_0$, $\omega_{sv} = \omega - \Gamma v_{0v}$. The equation of motion is written for corresponding parts of the stream as follows:

$$\begin{aligned} j\omega_s \tilde{v}(v_0) &= \frac{e}{m}\tilde{E}; \\ j\omega_{sv} \tilde{v}_v &= \frac{e}{m}\tilde{E}. \end{aligned} \qquad \text{(III.6)}$$

Substituting (III.2), (III.5) and (III.6) in the

equation of Poisson

$$-j\Gamma\widetilde{E}=\frac{\widetilde{\rho}}{\varepsilon_0}, \qquad \text{(III.7)}$$

we derive the dispersion equation:

$$\sum_{1}^{m}\frac{\omega_{p\nu}^2}{(\omega-\Gamma v_{0\nu})^2}+\frac{e^2}{\varepsilon_0 m^2}\int_{-\infty}^{\infty}\frac{f_0(v_0)}{(\omega-\Gamma v_0)^2}\,d v_0=1. \qquad \text{(III.8)}$$

This equation makes it possible by a preset function of electron velocity distribution to determine the constant distributions Γ.

2. Electron Streams with Discrete Velocity Distribution

The dispersion equation in this case has the form:

$$\sum_{\nu=1}^{m}\frac{\omega^2_{p\nu}}{(\omega-\Gamma v_0)^2}=1 \qquad \text{(III.9)}$$

and is an algebraic equation of degree 2 m relative to Γ. Analysis of it in general form presents difficulty. In [47] the graphic method is proposed, by means of which certain data can be derived concerning the roots of the dispersion equation of any degree. For this purpose the dispersion equation is written in the form:

$$f_1(a_1, \ldots, a_n, \Gamma, \omega) = f_2(b_1, \ldots, b_n, \Gamma, \omega).$$

Plotting of the graphs of curves $y_1(\Gamma) = f_1$ and $y_2(\Gamma) = f_2$ depending on Γ and finding projections of their intersection points gives real values of the dispersion equation roots: $\Gamma_1, \ldots, \Gamma_k$. With variation of ω, a_i, b_i, the curves $y_1(\Gamma)$ and $y_2(\Gamma)$ are deformed and displaced. If with variation of the parameters in pairs the intersection points of curves $y_1(\Gamma)$ and $y_2(\Gamma)$ vanish, then in addition to this we go from the range of real values Γ over to the range of complex values Γ which signifies the possibility of amplifying the waves of frequency ω in the given system. In this way the described graphic method makes it possible to define amplification boundaries with relative ease. It does not, however, afford the possibility of computing the system's amplification factor, since the values of the complex roots of the dispersion equation are not determined. Application of the described method to analysis of a traveling wave tube with a dielectric as retarding medium and to an electron wave tube [23,47,48] confirms the productiveness of the indicated method.

A detailed study of the dispersion equation for the particular case of the twobeam system

$$\frac{\omega_{p1}^2}{(\omega - \Gamma v_{01})^2} + \frac{\omega_{p2}^2}{(\omega - \Gamma v_{02})^2} = 1 \qquad \text{(III.10)}$$

was made in [49]. Equation (III.10) was computed for a wide range of parameter values and the calculation results are given in the form of graphs. The series of graphs represents the dependence of $\operatorname{Im}\Gamma \frac{v_{02}}{\omega_{p2}}$ on $\frac{\omega}{\omega_{p2}}$ in a number of values $\frac{\omega_{p1}}{\omega_{p2}}$ and $\frac{v_{01}}{v_{02}}$. The graphs for $\left(\frac{\omega_{p1}}{\omega_{p2}}\right)^2$ = 10.1; 0.001 are shown in Fig. 9 as examples.

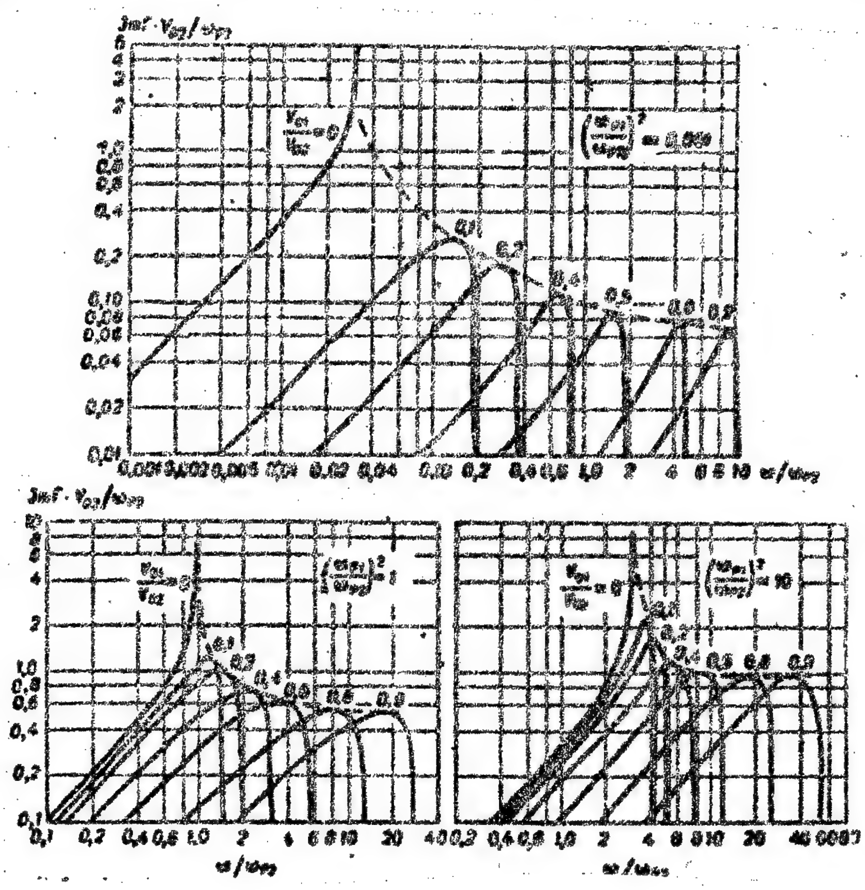

Fig 9

The least values $\left(\frac{\omega_{p1}}{\omega_{p2}}\right)^2$ describe well the stream of plasma in which the ions are no longer considered fixed [50]. Values $\left(\frac{\omega_{p1}}{\omega_{p2}}\right)^2$ of the order of unity are characteristic for the two-beam amplifier. Graphs of the Fig.9 type show that the imaginary component Γ (the growing wave)exists for the most varied combinations of parameters. It is interesting to note that the frequency at which maximal amplification is attained, feebly depends on $\left(\frac{\omega_{p1}}{\omega_{p2}}\right)^2$ but is chiefly determined by the ratio $\frac{v_{01}}{v_{02}}$. Another interesting fact is the presence of amplification with very small currents of a slow or fast beam ($\frac{\omega_{p1}}{\omega_{p2}}$ is very small or very great). This indicates the possibility of the two-beam type amplification at the expense of the emission from the control grid or secondary emission from the collector or positive grid in those tubes which are considered single beam [43,44]. Moreover, amplification at small ω_{p1}/ω_{p2} indicates the possibility of ionic oscillations even with small density of ions.

In the case of streams in the opposite direction $\left(\frac{v_{01}}{v_{02}} < 0\right)$ the range of amplifiable frequencies is drastically limited from above by the condition $\omega \approx \omega_{p2} = \omega_{p1}$ (Fig.10). The maximal amplification independent of the magnitude $\frac{v_{01}}{v_{02}}$ falls approximately on $\omega = \omega_{p2} = \omega_{p1}$. Analogous results in counter streams are cited in [47]

and [51].

In works [52] and [52] streams directed at an angle one to the other are examined. It is shown that the presence of cross motion of electrons contributes to the origin of space charge growing waves.

Electron streams with discrete velocity distribution have found practical application in the creation of two beam or electron wave tube (EWT). In [43] the dispersion equation of this device is investigated in the assumption $\omega_{p1}=\omega_{p2}$. Four values are derived for Γ. Two of them are complex conjugates in the range of values of nonhomogeneity parameter $\frac{\delta\omega}{v_{cp}\,\omega_{p1}}$ from zero to $\sqrt{2}$. Here $\delta = \frac{v_{01}-v_{02}}{2}$, $v_{cp} = \frac{v_{01}+v_{02}}{2}$. In the indicated range of the nonhomogeneity parameter values four waves of the space charge exist: two of constant amplitude, one attenuating and one growing. The latter also determines the EWT amplification.

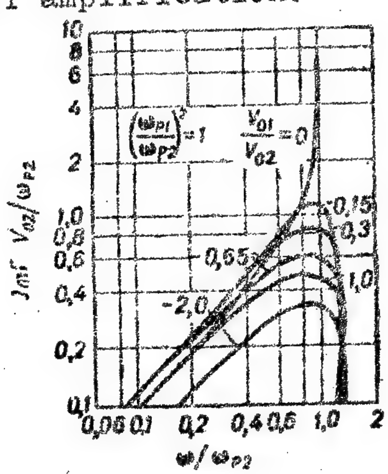

Fig. 10

Very many theoretical and experimental works have been devoted to the question of EWT amplification. The effect of the interaction of parallel electron streams was first explained by A.A. Vlasov [54,55]. In work [3] the multibeam tube is examined from the position of the Vlasov theory, taking into account velocity distribution. A number of works [43,56,57,58] have been devoted to the interaction of ideally mixed infinitely extensive electron streams in single velocity approximation. The space charge waves in two-beam systems of finite cylindrical cross section with ionic neutralization are studied in [23,45,48]. The effect of the degree of the space separation of beams on the space charge waves is examined in a number of works [59,60,61]. In [51] it is indicated that the four waves in EWT are not independent but must be connected with the preset boundary conditions. Works [62,63,64] are devoted to making more precise the EWT theory in the direction of taking the thermal motion of electrons and noises into account. Article [65] is a survey of EWT theories based on [58]. Noteworthy among experimental works on EWT are [43,66,67].

3. Electron Streams with Continuous Velocity Distribution

Space charge waves in streams with continuous

velocity distribution are described by dispersion equation (III.8) without the first term. For further analysis, it is more convenient to write the equation in the form:

$$\frac{e^2}{m v_0 \Gamma^2}\int_{-\infty}^{\infty}\frac{\frac{\partial f_0(v_0)}{\partial v_0}d v_0}{v_0-\frac{\omega}{\Gamma}}=1. \qquad \text{(III.11)}$$

It is convenient to replace Maxwell's velocity distribution by the pi distribution [3] which reflects well the fact of the presence of a finite range of velocities and one maximum. The electrons have a velocity spread of $\pm\frac{\Delta v}{2}$ near the average value v_{01}.

The distribution function can, by means of the δ-function, be written as follows:

$$f_0(v_0)=\frac{N}{\Delta v}\left\{\int_{-\infty}^{\infty}\delta\left(v_0-v_{01}+\frac{\Delta v}{2}\right)d v_0-\int_{-\infty}^{\infty}\delta\left(v_0-v_{01}-\frac{\Delta v}{2}\right)\times\right.$$
$$\left.\times d v_0\right\}, \qquad \text{(III.12)}$$

in which N is the number of electrons in a unit of volume.

Differentiating (III.12) in v_0 and substituting the result in (III.11), we find

$$\Gamma=\frac{\omega v_{01}\pm\sqrt{\omega_p^2 v_{01}^2+\frac{\omega^2\Delta v^2}{4}-\omega_p^2\frac{\Delta v^2}{4}}}{v_{01}^2-\frac{\Delta v^2}{4}}. \qquad \text{(III.13)}\ 3)$$

Since $\omega_p \ll \omega$ is usual, both values of Γ are real. Consequently, in the stream with velocity distribution of the Maxwell type, there are no growing waves. The author [45] who examined the distribution function with one extreme came to a similar conclusion.

A function of electron velocity distribution having several maximums can be well represented by the equivalent multistage pi distribution (Fig. 11), in which the number of plane sections is equal to the number of extremes in continuous distribution. Considerations analogous to the foregoing lead to the dispersion equation

$$\sum_{\nu=1}^{m} \frac{\omega_{p\nu}^2}{(\omega - \Gamma v_{0\nu})^2 - \Gamma^2 \left(\frac{\Delta v_\nu}{2}\right)^2} = 1. \qquad \text{(III.14)}$$

Here m is the number of pi peaks in the equivalent distribution function.

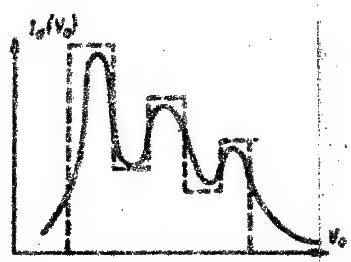

Fig. 11

The equation (III.14), the analogue of the correlation (III.9), is an algebraic equation of the degree of 2m relative to Γ and has complex roots. The presence in the distribution function of not less than two maximums is thus the condition of the presence of growing waves in a beam with continuous velocity distribution. Such an electron beam can be considered multivelocital with the number of separate beams equal to the number of relative maximums in the distribution function [45].

It is appropriate here to recall the results of the analysis of the electron stream with bending deflection of the potential (see section II.4). The distribution function for this stream does not have two maximums, which explains the absence of growing waves in this case. In such a beam the phase velocities of the space charge waves lie outside the range of electron velocities.

In streams having two and more maximums in the distribution function, growing waves of a space charge are possible with phase velocites lying inside the range of velocity distribution.

An interesting method of dispersion equation (III.11) analysis is developed in [68].

In the work [69] a plasma stream with velocity distribution is investigated with consideration of collisions.

It was found that collisions and the attenuation caused by them play an essential role in the oscillation processes in plasma. In particular, complex values appear for Γ in those cases when without attenuation Γ assumes only actual values. In those cases, therefore, when it is impossible to disregard collisions, the results [69] have important significance. It can be presumed that collisions modify the electron velocity distribution function in a way that relative maximums and minimums appear and amplification of space charge waves becomes possible. This phenomenon can prove to be one of the reasons for the amplification in the single beam tube [43].

In (70) the need is substantiated for stricter analysis of the beam with continuous velocity distribution: with the use of exponential substitution (II.6) a divergent integral is derived (55) in the dispersion equation and three families of solutions are lost. For stricter solution of the problem, the operational method of solving the initial equations [70,71,72,73] is employed in a number of works. The final results in these works are a great deal more complex than those derived by means of (II.6); however, they do not contradict the main conclusions reached above.

In [74] the effect of velocity spread on the

high frequency processes in the electron stream is investigated by a singular method. It is assumed that the presence of a range of electron velocities can be considered in the framework of a single-velocity approximation, introducing in acceleration an additional term connected with the hydrostatic pressure in the beam with velocity spread. It is demonstrated that the presence of velocity distribution increases the effective plasma frequency

$$\omega_{s\,экв} = \omega_s \sqrt{1 + \frac{kT_к}{m v_0^2}\left(\frac{\omega}{\omega_s}\right)^2}. \qquad \text{(III.15)}$$

a - equivalent

Here k is Boltzmann's contant; T_k is the cathode's absolute temperature.

A method of investigating streams with velocity distribution based on the Liouville theorem, is developed in [75,76]. The method is good also for analysis of accelerated streams with velocity distribution.

4. Electron Streams with Uniform Velocity Change in the Travel Direction

In the case examined the method of analysis differs from the foregoing, since by virtue of the dependence of v_0 on z it is not possible further to employ the

exponential substitution (II.6) or (II.34).

Various approaches to solution of the problem can be used depending on the method of defining the function $v_0(z)$. In those cases when $v_0(z)$ is defined by the results of experiment (for example) measurements in an electrolytic bath), or the analytical expression for $v_0(z)$ is too complex, it is convenient to use the equations of Llewellyn for the planar diode, connecting the values $\tilde{i}$ and $\tilde{v}$ at the input with their values at the output of the diode [77,78,79]. The Llewellyn equations are developed for the electron stream with the longitudinal bending deflection of potential (without ionic compensation); for use of it in the given case, therefore, the stream is divided into a series of short segments following one another, each of which is viewed as an independent diode with definite conditions at the input and the output. The trend of the potential, derived in this way, (the dotted line in Fig.12), appoximately reflects the real trend of the potential (the solid line in Fig 12). It is very convenient to write the solution in matrix form, since the matrix of the cascade of diodes is equal to the product of the matrices of the individual diodes, and these latter matrices are derived from the Llewellyn equations [79,80].

The composition and solution of differential

equations for $\tilde{i}$ and $\tilde{v}$ is another method of solving the problem. The stream is assumed to be one-dimensional

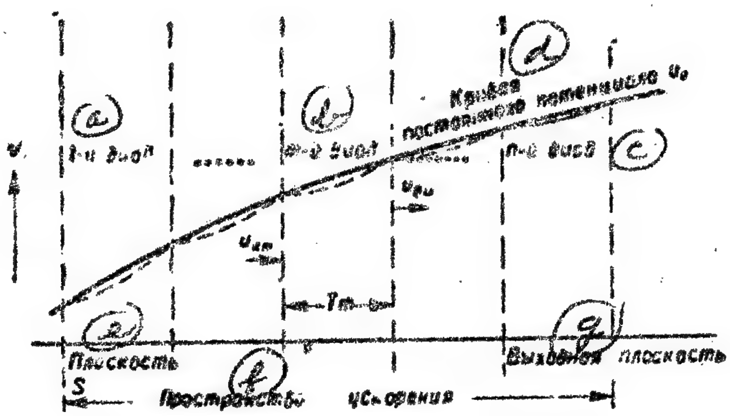

Fig. 12.

a - first diode

b - third diode

c - fifth diode

d - curve of constant potential

e - plane

f - output plane

g - space of acceleration

(this assumption is discussed in detail in [81]), the signal small. The equations of full current, motion, ratio for $\tilde{i}$ and continuity equation are utilized:

$$\tilde{I} + j\omega\varepsilon_0 c \tilde{E} = \tilde{I}_{\text{полн}}; \qquad \text{(III. 16)}$$

a - full

$$j\omega\tilde{v} + \frac{\partial}{\partial z}\left(v_0\tilde{v}\right) = \frac{e}{m}\tilde{E};\tag{III.17}$$

$$\tilde{i} = \tilde{\rho}\, v_0 + \tilde{v}\rho_0,\tag{III.18}$$

$$\frac{1}{\sigma}\frac{\partial\tilde{I}}{\partial z} = -j\omega\tilde{\rho}.\tag{III.19}$$

Here σ is the transverse cross section of the stream; $\tilde{I} = \sigma\tilde{i}$ is the convection current and

$$I_0 = \sigma\rho_0 v_0 = \text{const}.\tag{III.20}$$

Further, the assumption about the slow variation of σ along the current is used [82].

Excluding $\tilde{E}$ from (III.16) and (III.17) and $\tilde{\rho}$ from (III.18) and (III.19), we find

$$\frac{d\tilde{I}}{dz} v_0 = j\,\sigma\omega\,\tilde{v}\,\rho_0 - j\omega\tilde{I};\tag{III.21}$$

$$j\frac{e}{m\omega\varepsilon_0\sigma}\tilde{I} = j\omega\tilde{v} + \frac{\partial}{\partial z}\left(v_0\tilde{v}\right).\tag{III.22}$$

In the development of (III.21) and (III.22), it is presumed that $\tilde{I}_{full} = 0$. This can be done if outside e.m.f. of any kind is absent on the beam boundaries. The

case of $\tilde{I}_{full} \neq 0$ is examined in [83].

The equations (III.21) and (III.22) are simplified, if the following substitution is taken for the current:

$$\tilde{I} = J(z)\, e^{j\omega(t-\tau)}, \qquad \text{(III.23)}$$

in which

$$\tau(z) = \int^{z} \frac{dz}{v_0(z)}. \qquad \text{(III.24)}$$

Taking (III.23) and (III.24) into account, the equations (III.21) and (III.22) assume the form:

$$\tilde{v} = -j \frac{v_0^2}{\omega I_0} \frac{dJ}{dz} e^{j\omega(t-\tau)}; \qquad \text{(III.25)}$$

$$\frac{d^2 J}{dz^2} + \frac{3}{v_0} \frac{dv_0}{dz} \frac{dJ}{dz} + \frac{e I_0}{m \varepsilon_0 \sigma v_0^3} J = 0. \qquad \text{(III.26)}$$

The solution of these equations is found possible for certain concrete functions $v_0(z)$. For $v_0 =$ const the solution has been given in the works [1,2] and many subsequent ones; for $v_0 = Kz^{2/3}$ in [83]; for $v_0 = Kz^{\frac{1}{2}}$ in [79]; for $v_0 = Kz^{a}$ in [84].

By virtue of the assumption about the linearity of the processes examined, the connection of values at the system's input and output looks so:

$$\tilde{i} = (E\, i_1 + F\, v_1)\, e^{j\omega(t-\tau)};$$
$$\tilde{v} = (H\, i_1 + I\, v_1)\, e^{j\omega(t-\tau)}. \qquad \text{(III.27)}$$

The coefficients E,F,H,I characterize the behavior of space charge waves. According to [84], the solutions of equations (III.25) and (III.26) for $v_0 = Kz^{\alpha}$ give the following expressions for the coefficients:

$$E = \frac{\pi \gamma x_1}{2}\left(\frac{x}{x_1}\right)^{\frac{1-3\alpha}{2-3\alpha}}[N_p(\gamma x) J_{p+1}(\gamma x_1) - J_p(\gamma x) N_{p+1}(\gamma x_1)];$$
$$F = jG\frac{\pi \gamma x_1}{2} x^{\frac{1-3\alpha}{2-3\alpha}} x_1^{\frac{2\alpha-1}{2-3\alpha}}[N_p(\gamma x) J_p(\gamma x_1) - J_p(\gamma x) N_p(\gamma x_1)]; \qquad \text{(III.28)}$$
$$H = j\frac{1}{G}\frac{\pi \gamma x_1}{2} x^{\frac{1-2\alpha}{2-3\alpha}} x_1^{\frac{3\alpha-1}{2-3\alpha}}[N_{p+1}(\gamma x) J_{p+1}(\gamma x_1) - J_{p+1}(\gamma x) N_{p+1}(\gamma x_1)];$$
$$I = \frac{\pi \gamma x_1}{2}\left(\frac{x}{x_1}\right)^{\frac{1-2\alpha}{2-3\alpha}}[N_{p+1}(\gamma x) J_p(\gamma x_1) - J_{p+1}(\gamma x) N_p(\gamma x_1)].$$

Here $\gamma^2 = \frac{e I_0}{m \varepsilon_0 \sigma k^3}\frac{4}{(2-3\alpha)^2}$; $G = \omega\sqrt{\frac{m I_0 \sigma \varepsilon_0}{e k}}$; $x = z^{\frac{2-3\alpha}{2}}$;

I_p and N_p are Bessel functions of I and II type.

A graph of coefficients (III.28) are cited in [79] for the case $\alpha = \frac{1}{2}$. The factors increase with motion of the electron stream in a retarding field and are decreased with motion in an accelerating field.

The equation (III.28) can be represented in a form more convenient for discussion, by employing an approximated expression of the Bessel functions through the trigonometric functions for the large values of the

arguments γx and γx_1 [85]. The indicated substitution is possible in case of $-0.2 \ll \alpha \ll \frac{2}{3}$ [84]. Then we have:

$$
\begin{aligned}
E &= \left(\frac{x}{x_1}\right)^{\frac{3\alpha}{6\alpha-4}} \cos\gamma(x - x_1); \\
F &= jG\, x_1^{-\frac{\alpha}{6\alpha-4}}\, x^{\frac{3\alpha}{6\alpha-4}} \sin\gamma(x - x_1); \\
H &= j\frac{1}{G}\, x_1^{-\frac{3\alpha}{6\alpha-4}}\, x^{\frac{\alpha}{6\alpha-4}} \sin\gamma(x - x_1); \\
I &= \left(\frac{x}{x_1}\right)^{\frac{\alpha}{6\alpha-4}} \cos\gamma(x - x_1).
\end{aligned}
\tag{III.29}
$$

From the equations (III.29) it follows that in the accelerating fields $\left(0 < \alpha < \frac{2}{3}\right)$ space charge waves attenuate. In drifting streams ($\alpha = 0$) the amplitude of space charge waves is not changed and, as should also be expected, the expressions for $\tilde{i}$ and $\tilde{v}$ from (III.27), taking into account the initial conditions $x_1 = 0$; $\tilde{i}(x_1) = 0$; $\tilde{v}(x_1) = 2v_1$ and the equations (III.29), coincide with expressions for $\tilde{i}$ and $\tilde{v}$ from (II.13) and (II.15). Finally, with $-0.2 < \alpha < 0$, in the retarding fields, the space charge waves are amplified with distance.

The effect of the thermal motion of electrons for the case $v_0 = ke^{-\alpha z}$ is examined in [86]. It is found that amplification of space charge waves is possible with fulfilment of the conditions

$$\alpha \gg \frac{\omega_p}{v_0}; \quad \alpha \gg \frac{\omega v_T}{v_0^2}.$$

in which v_T is the thermal velocity of electrons. From these conditions, it is evident that sufficiently strong retardation is essential for amplification, and that the amplification depends on the frequency owing to the presence of $v_T \neq 0$. With growth of frequency the second condition of amplification ceases to be fulfilled.

The attenuation of space charge waves in accelerated streams is utilized for lowering the noise level in super-high frequency devices. Growing space charge waves in retarded streams make it possible to realize the amplification of super-high frequency signals in tubes with jump of potential [79,87,88,89].

It follows from the foregoing that the cases $v_0(z) = kz^2$ and $v_0(z) = ke^{-az}$ have been solved analytically. In more complex cases the use of a definite analogy betweem the electron stream and the transmission line is found productive [82]. This analogy consists in the point that the equations for the space charge waves in an electron beam can be written in a form that is identical for the transmission line equations. In order to do this, it is necessary to proceed from the variable electron velocity $\tilde{v}$ to the variable potential $\tilde{u}$, introduced by the ratio

$$e\left(u_0+\tilde{u}\right)=\frac{m}{2}\left(v_0+\tilde{v}\right)^2\approx\frac{m}{2}\left(v_0^2+2v_0\tilde{v}\right).$$

from which

$$\tilde{u} = \frac{m}{e} v_0 \tilde{v} \ . \qquad \text{(III.30)}$$

Representing $\tilde{u}$ in the form $U(z)e^{j\omega(t-\tau)}$, we derive for amplitudes of space charge waves $U(z)$ and $I(z)$ from equations (III.25) and (III.26) the following relationships:

$$\frac{dU}{dz} = -\frac{j}{\omega\varepsilon_0 S} I,$$

$$\frac{dI}{dz}\ j\varepsilon_0\omega S\left(\frac{\omega_s}{v_0}\right)^2 U. \qquad \text{(III.31)}$$

The magnitude $\omega_s = s\omega_p$ is here introduced for calculation of finitnesses of stream dimensions and the effect of surrounding walls.

It should be noted that the equations (III.31) describes only the amplitude envelope of space charge waves, i.e. amplitude modulation along axis z of the electron wave represented by multiplier $e^{j\left(\omega t - \omega\int\frac{dz}{v}\right)}$ Equations (III.31) can be transformed to:

$$\frac{dU}{d\varphi} = jWI;$$

$$\frac{dI}{d\varphi} = j\frac{1}{W}U, \qquad \text{(III.32)}$$

in which $W = \frac{2U_0}{I_0}\frac{\omega_s}{\omega}$ is the stream wave resistance; $\varphi = \int_0^z \beta(z)\,dz$ is the electrical length of

the stream; $\beta = \frac{\omega_s}{v_0}$ - is the constant propagation.

The equations describing the wave propagation along an electron stream with varying constant parameters are thus formally identical with equations of transmission lines having variable wave resistance. To obtain data on the behavior of space charge waves in the streams, the picture can therefore be used of standing waves in a model, a coaxial line, the internal conductor of which changes diameter in accordance with $W(\varphi)$ of the stream. Testing of the work of a transmission line as a modelling device for an electron beam was conducted [82] in the example of a planar diode and showed that the experimental data tallied well with the theoretical results.

5. Electron Streams with Periodic Structure

Especially interesting results have been attained in recent years in the study of space charge waves in electron streams with periodically changing characteristics [8, 86, 90 - 93]. Periodic change of the characteristics of an electron stream along any coordinate can be realized either by periodic change of the constant parameters along a staight line stream (Fig. 13) or by zigzag beam shape along the examined coordinate (Fig. 14).

Since the examination of an electron stream with

arbitrary periodic change of parameters is impossible, selection of a case open to analysis and at the same time sufficiently general, has sense. Let us assume that the electron stream consists of periodically repeating uniform segments with the electron velocities in them v_{01} and v_{02} and the wave resistances W_1 and W_2 (Fig.15).

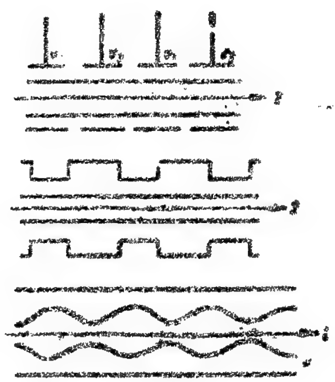

Fig. 14.

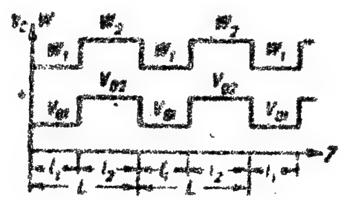

Fig. 13.

Fig. 15.

Proceeding in (III.21) and (III.22) from $\widetilde{v}$ to $\widetilde{u}$, according to (III.30), we derive:

$$\frac{d\widetilde{I}}{dz} + j\frac{\omega}{v_0}\widetilde{I} - j\frac{a\,\omega\,\rho_0\,e}{m\,v_0^2}\widetilde{u} = 0;$$

$$\frac{d\widetilde{u}}{dz} + j\frac{\omega}{v_0}\widetilde{u} - j\frac{1}{\omega\,\varepsilon_0\,\sigma}\widetilde{I} = 0. \qquad \text{(III.33)}$$

Excluding $\widetilde{I}$ from one equation, and $\widetilde{u}$ from the other, two differential linear equations of the second order with

periodic coefficients can be derived. Particular solutions of them satisfy the conditions:

$$\tilde{I}(z+L)=\tilde{I}(z)\,e^{-j\psi};\qquad\qquad (III.34)$$
$$\tilde{u}(z+L)=\tilde{u}(z)\,e^{-j\psi},$$

(in which L is the period (Fig.15)), and have the form:

$$\tilde{I}(z)=\sum_{n=-\infty}^{\infty} i_n\, e^{-j\frac{\psi+2\pi n}{L}z};$$
$$\tilde{u}(z)=\sum_{n=-\infty}^{\infty} u_n\, e^{-j\frac{\psi+2\pi n}{L}z}, \qquad\qquad (III.35)$$

in which i_n and u_n are constant complex values in the general case.

The sense of equations (III.35) consists in the point that the high frequency current $\tilde{I}$ and the high frequency potential $\tilde{u}$ are represented by an infinite sum of space harmonics of current and potential [8,91,93] with constants of propagation.

$$\Gamma_n=\frac{\psi+2\pi n}{L}, \qquad\qquad (III.36)$$

in which ψ is the phase shift in one period for the fundamental wave. In order to solve the question of the propagation velocity and character of the change of the amplitude of space harmonics with distance, an expression for

ψ must thus be found. In the general case ψ is complex; at the same time the actual part of ψ determines the phase velocity of the space harmonic

$$v_{\phi n} = \frac{\omega L}{\mathrm{Re}\,\psi + 2\pi n}, \qquad \text{(III.37)}$$

while the imaginary part of ψ characterizes the change in the amplitude of the space harmonic of current and voltage along the beam:

$$i_n\, e^{\frac{\mathrm{Im}\,\psi}{L} z}, \quad u_n\, e^{\frac{\mathrm{Im}\,\psi}{L} z}.$$

We calculated the phase shift for the selected jump-shaped periodic change of the velocity of electrons (Fig.15). For each uniform section of the stream (III.32) can be written, proceeding from U and $\tilde{J}$ to u and $\tilde{I}$.

$$\tilde{I}_{1,2}(x) = \left(j \frac{1}{W_{1,2}} u_n \sin \frac{\omega_{g1,2}}{v_{01,2}} x + I_n \cos \frac{\omega_{g1,2}}{v_{01,2}} x \right) e^{-j\frac{\omega}{v_{01,2}} x};$$

$$u_{1,2}(x) = \left(u_n \cos \frac{\omega_{g1,2}}{v_{01,2}} x + j W_{1,2} I_n \sin \frac{\omega_{g1,2}}{v_{01,2}} x \right) e^{-j\frac{\omega}{v_{01,2}} x},$$

(III.38)

where I_H and u_H are respectively current and voltage at the beginning of this section. The coordinate $x = z - z_{i0}$ is reckoned from the beginning of the i section examined.

For the first segment (Fig.15) $I_H = \tilde{I}(0)$, $u_H = \tilde{u}(0)$ and according to (III.38):

$$\tilde{I}_1(l_1) = \left[j\tilde{u}(0)\frac{1}{W_1}\sin\frac{\omega_{s1}}{v_{01}}l_1 + \tilde{I}(0)\cos\frac{\omega_{s1}}{v_{01}}l_1 \right] e^{-j\frac{\omega l_1}{v_{01}}};$$

$$\tilde{u}_1(l_1) = \left[\tilde{u}(0)\cos\frac{\omega_{s1}}{v_{01}}l_1 + jW_1\tilde{I}(0)\sin\frac{\omega_{s1}}{v_{01}}l_1 \right] e^{-j\frac{\omega l_1}{v_{01}}}. \qquad \text{(III.39)}$$

At the point of wave resistance jump, current and potential are continuous. On different sides of the jump the laws of standing wave change are different, but the values of current and voltage with approach to the jump point from both sides coincide. Thus, the initial conditions for the second segment will be: $u_H = \tilde{u}_1(l_1)$; $I_H = \tilde{I}_1(l_1)$. Hence

$$\tilde{I}_2(L) = \left[j\frac{1}{W_2}\tilde{u}(l_1)\sin\frac{\omega_{s2} l_2}{v_{02}} + \tilde{I}(l_1)\cos\frac{\omega_{s2} l_2}{v_{02}} \right] e^{-j\frac{\omega}{v_{02}}l_2};$$

$$\tilde{u}_2(L) = \left[\tilde{u}(l_1)\cos\frac{\omega_{s2} l_2}{v_{02}} + jW_2\tilde{I}(l_1)\sin\frac{\omega_{s2} l_2}{v_{02}} \right] e^{-j\frac{\omega}{v_{02}}l_2}. \qquad \text{(III.40)}$$

Substituting (III.39) in (III.40), $\tilde{I}_2(l)$ and $\tilde{u}_2(l)$ can be expressed through $\tilde{I}(0)$ and $\tilde{u}(0)$. Moreover these same values are connected with the relationships (III.34). The condition of consistency of these four equations with four unknowns gives the equation for ψ:

$$\cos(\psi - \psi_0) = \alpha \qquad \text{(III.41)}$$

in which (III.42)

$$\alpha = \cos\theta_1\cos\theta_2 - \frac{1}{2}\left(\frac{W_2}{W_1} + \frac{W_1}{W_2}\right)\sin\theta_1\sin\theta_2$$

and

$$\Theta_1 = \frac{\omega_{s1} l_1}{v_{01}}, \; \Theta_2 = \frac{\omega_{s2} l_2}{v_{02}}, \; \psi_0 = \frac{\omega l_1}{v_{01}} + \frac{\omega l_2}{v_{02}}. \qquad \text{(III.43)}$$

For analysis of the solution derived, two cases should be examined. 1. $|\alpha| \ll 1$.

Besides

$$\begin{aligned} \operatorname{Re}\psi &= \psi_0 \pm |\arccos \alpha|, \\ \operatorname{Im}\psi &= 0. \end{aligned} \qquad \text{(III.44)}$$

This means that with $|\alpha| \ll 1$ two fundamental waves are possible with slightly differing phase velocities (analogous to the earlier known fast and slow waves of the space wave), and accordingly two systems of spatial harmonics. The amplitudes of waves along the stream are not changed. The phase velocities of the harmonics have the form:

$$v_{\Phi n} = \frac{\omega L}{\psi_0 \pm |\arccos \alpha| + 2\pi n}. \qquad \text{(III.45)}$$

The magnitude $|\arccos\alpha|$ depends on the space charge density and its role is similar to the role of ω_p in (II.12).

2. $|\alpha| > 1$.

In this case

$$\operatorname{Re}\psi = \begin{cases} \psi_0 & \text{при } \alpha > 0; \\ \psi_0 - \pi & \text{,, } \alpha < 0, \end{cases} \qquad \text{(III.46)}$$

$$\operatorname{Im}\psi = \pm \ln\left(|\alpha| + \sqrt{\alpha^2 - 1}\right).$$

From the relationships (III.46) it follows that with $|\alpha| > 1$ there are two fundamental waves (accordingly, two systems of space harmonics), one with growing, the other with declining amplitude with distance. The phase velocities of waves of one order n are identical. The amplitude change occurs according to the law

$$e^{\pm \ln\left(|\alpha| + \sqrt{\alpha^2 - 1}\right)\frac{z}{L}}$$

and in one period amounts to

$$\left|\frac{\tilde{u}(L)}{\tilde{u}(0)}\right| = \left(|\alpha| + \sqrt{\alpha^2 - 1}\right)^{\pm 1}. \qquad \text{(III.47)}$$

For the case $\Theta_1 = \Theta_2 = \frac{\pi}{2}$ and the initial condition $\tilde{I}(0) = 0$ (III.47) gives:

$$\left|\frac{\tilde{u}(L)}{\tilde{u}(0)}\right| = \frac{W_2}{W_1}. \qquad \text{(III.48)}$$

In this way depending on the ratio of wave resistances, either amplification or attenuation of space charge waves can be produced.

Fig. 16 a, b illustrate the picture of events in such a periodic electron stream. Standing waves of variable potential (or velocity) and current occur in each uniform segment of the electron stream. With the

selected initial conditions and the assumption $W_2 > W_1$ (Fig. 16,a) the maximums of the variable component of velocity are arranged at points A,C,E,... of the stopping potential jump. With retardation of electrons according to the law of energy conservation, one can find:

$$\frac{\tilde{v}_b}{\tilde{v}_a} = \frac{v_{0a}}{v_{0b}} \qquad \text{(III.49)}$$

(index a refers to the values before the potential jump, index b to the values after the jump).

In accordance with (III.49) and the conclusions of the preceding section, with retardation of the electron stream the variable velocity component increases. At the points B,D,... the constant component of velocity by a jump increases to its former value. This does not lead to a change of the variable component, since at the points indicated its amplitude passes through zero. The velocity modulation which has been increased in the retarding jump leads to an increase of the beam density modulation. So in series occurs the stepped amplification of the space charge waves.

If under the same initial conditions, $W_2 < W_1$ (Fig.16,b) is assumed, then the maximums of the variable velocity component will correspond to the accelerating

jump of potential, and in this case stepped attenuation of the space charge waves will occur.

It should be noted that amplification or attenuation of space charge waves is possible also with stepless periodic change of the electron stream parameters.

Periodic change of stream wave resistance W can be achieved by various methods. From the correlation

$$\frac{W_2}{W_1} = \frac{U_{01} s_1 \omega_{p1}}{U_{02} s_2 \omega_{p2}} \qquad (III.50)$$

it is evident that there are at least four possibilities for changing the wave resistance: (1) periodic change of accelerating voltage (such a way is employed in the tube with velocity jumps for purposes of amplifying super high frequency signals [79,87,88] and reduction of noises in traveling wave tubes [94]; (2) periodic change in the diameter of drift tubing (this is reflected in the magnitude of the plasma frequency reduction factor S [95]; (3) periodic change in the beam diameter which influences the values s and ω_p ; This possibility is easily realized by "shooting" the electron stream in a longitudinal magnetic field with initial radial velocities of electrons present; the works [95,96] are devoted to investigation of amplifiers with periodically changing beam diameter; (4)

periodic change of concentrations of ions in the plasma which penetrates the electron stream [97]. It is evident that the most effective amplification or attenuation of space charge waves can be obtained by way of the combination of several methods, which leads to a big jump of wave resistance.

The possibility noted above of using a non-homogeneous transmission line for modelling an electron beam is also quite applicable to the electron stream with periodic structure. The analogue of such a beam is a line with periodic change of wave resistance. At the same time the areas of amplification of space charge waves (or the attenuation of them) correspond to blanking bands of the equivalent filtering line; while areas of waves of invariable amplitude correspond to passing bands of the filtering line. Equivalent filtering lines were investigated in [90] and it was noted that inside the blanking band predominates either amplification or attenuation of the wave, which depends on the final full resistance z_a. If $z_A \equiv \frac{V_a}{I_a} = \infty$, there is optimal amplification. Only amplification is possible along the infinitely long beam.

From the energy viewpoint, amplification in the periodic stream should be understood as parametric. The setting of the maximum of the stream's variable component of velocity in the retarding jump of potential, and

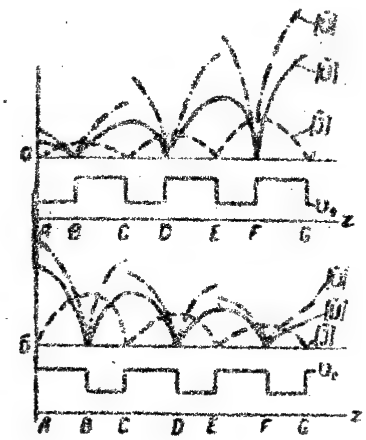

Fig. 16

of the velocity zero in the potential's accelerating jump is analogous to extension of the plates of a tank capacitor at the moment of greatest voltage in the capacitor and drawing the plates together at the moment when the voltage in the capacitor passes through zero. It is evident that for optimal amplification (or attenuation) of the space charge waves, an odd number of a quarter plasma wave length should be chosen between adjacent potential jumps: $(2K + 1)\frac{\lambda_{s1}}{4}$ in the segment l_1 and $(2m + 1)\frac{\lambda_{s2}}{4}$ in the segment l_2. At the same time

$$L = n\frac{\lambda_s}{2}, \tag{III.51}$$

in which $n = (2K + 1) + (2m + 1)$. Such a correlation between the space period of the parameter change and

the wave length of the system's natural oscillations is known to be characteristic for parametric oscillations.

It is possible to realize also another method of parametric amplification [98,99] which is analogous to parametric amplification in a transmission line. In an ideal transmission line having distributed inductance per unit of length on the kind:

$$L = L_0 [1 + \eta \sin 2 (\omega t - \Gamma z)] \qquad (III.52)$$

and constant distributed capacitance C_0 per unit of length, growing waves of current arise:

$$\tilde{i} = i_0 e^{\alpha z} \sin (\omega t - \beta z + \varphi) , \qquad (III.53)$$

in which

$$\alpha = \omega \sqrt{L_0 C_0} \frac{\eta}{4} \cos 2 \varphi ; \qquad (III.54)$$

$$\beta = \omega \sqrt{L_0 C_0} \left(1 - \frac{\eta}{4} \sin 2 \varphi\right) . \qquad (III.55)$$

Besides the energy of the growing wave is taken from a source modulating the line's inductance with a frequency of 2ω.

In application to the electron beam, it is evident that modulation of it in velocity and density with a frequency of 2ω is sufficient to produce a similar effect of amplification. Analysis [99] shows that in this case the slow and fast wave of the space charge become

one, the growing, the other, decreasing. Amplification of both the fast and the slow wave can thus be produced. The latter is possible only because the power is taken not from the electron stream, but from the source of frequency 2ω modulation. It is expected that the noises of the fast wave amplifier will be lower than other types of space charge wave amplifiers.

Another interpretation of oscillation phenomena in electron streams also exists, from the viewpoint of the coupling of space charge waves [7,8,10]. Let us examine the question of the coupling of waves of different types [10] and clarify the general conditions of amplification of space charge waves (Fig. 17). Two waves with amplitudes P and Q are propagated from left to right. The magnitudes P and Q are so chosen that PP^* characterizes the power flux of wave P, while $\pm QQ^*$ is the power flux of wave Q. The top sign, plus, is selected if the power of the waves flows in one direction, the lower sign, minus, if the power flux is directed to diverse sides.

Fig. 17.

a - transition

The coupling of the waves is realized in the transition and is described by the equations:

$$P_d = A P_a + B Q_a, \qquad Q_d = C Q_a + D P_a. \tag{III.56}$$

and also by the law of energy conservation

$$P_a P_a^* \pm Q_a Q_a^* = P_d P_d^* \pm Q_d Q_d^*. \tag{III.57}$$

Here P_a and Q_a are the amplitudes of waves from the left to the transition, at the system output, and P_d and Q_d are the amplitudes of waves from the right to the transition at the output; r_1, r_2, r_3 and r_4 are planes of the count beginning.

Analysis of equations (III.56), (III.57) taking into account phase shifts in the transition itself and in the whole section between the count planes leads to the following conclusions: (1) if the power flux is directed to one side, then as a result of the coupling continuous traveling waves are produced; there are no amplifying waves; (2) if the power flux is directed to different sides, then waves are possible with an amplitude changing exponentially with distance. It should be noted that these conclusions refer to a chain of such transitions as shown in Fig.17, i.e. to a periodic coupling of waves. The continuous coupling of waves is produced in a limit, with a very

large number of very closely situated transitions.

In order that the waves be coupled, i.e. that they might interact, the interpenetration of the fields of these waves and approximate equality of their phase velocities (synchronism) are essential. In the case of periodic coupling the formulated condition of synchronism must be imposed on the corresponding space harmonics of the coupled waves. But if the device of resolution in space harmonics is not used, then the condition of the coupling of two waves is modified. When in the transition itself the phase shifts are small (as, for example, in the tube with velocity jumps), then the best coupling is produced with phase difference of waves Φ and Q by a coupling period equal to $2\pi n$. By means of periodic interaction, waves with greatly differing velocities can thus be coupled. The more intense the interpenetration of the wave fields, the broader the range of the change of parameters near $\Delta\varphi = 2\pi n$ (for the periodic coupling) or $\Delta\varphi \approx 0$ (for continuous coupling), for which amplification of space charge waves is possible.

As was already noted, amplification of space charge waves is possible only in case of power fluxes in opposite direction. This is possible in the case when the wave is propagated in a moving beam. In section II.1 it was

demonstrated that the slow wave of a space charge bears negative power. Thus, to get a space charge wave with exponentially changing amplitude, it is sufficient to couple the slow wave of the space charge with any kind of wave bearing positive power. This is done in a number of electron-wave devices. In the EWT, for example, continuous interaction is achieved of the slow wave of a fast stream's space charge and the fast wave of a slow stream's space charge. The proximity of the phase velocities of these waves and the good scrambling of streams are conditions of optimal amplification. In tubes with varied kind of wave resistance jumps, the slow and fast waves of one and the same electron stream are coupled. Since the phase velocities of these waves differ appreciably, the coupling between them is achieved by means of periodic nonuniformities, wave resistance jumps. The phase difference of the slow and fast waves by the period L (Fig.15) with $l_1 = \frac{\lambda_{s1}}{4}(2K+1)$ and $l_2 = \frac{\lambda_{s2}}{4}(2m+1)$ is found equal to $2\pi n$, in full accordance with the amplification condition set forth above.

Let us now examine periodic interaction in the circuit with wave resistance jumps by the other method indicated above, by means of coupling the space harmonics. According to (III.45) the phase velocities of them are,

in the absence of amplification, equal to

$$v_{\phi n} = \frac{\omega L}{\psi_0 \pm |\operatorname{arc\,cos} \alpha| + 2\pi n}$$

Introducing the retardation magnitude $\frac{c}{v_{\phi n}}$ and $\lambda_0 = \frac{2\pi c}{\omega}$, we derive the dispersion equation in its usual form of writing:

$$\frac{c}{v_{\phi n}} = \frac{c}{L}\left(\frac{l_1}{v_{01}} + \frac{l_2}{v_{02}}\right) \pm$$
$$\pm \frac{\lambda_0}{L}\frac{|\operatorname{arc\,cos} \alpha|}{2\pi} + n\frac{\lambda_0}{L}. \qquad \text{(III.58)}$$

The corresponding dispersion diagram is given in Fig.18. The solid lines are space harmonics of the space charge's fast wave; they carry positive power. The dashed lines correspond to the space harmonics of the space charge's slow wave; they carry negative power. The condition of amplification will be the coincidence of the phase velocity of the fast wave's n harmonic with the slow wave's $(n + m)$ harmonic. According to (III.58) this leads to the condition $\alpha = \pm 1$, which corresponds to the boundary of amplification. In [6] this question is examined with certain simplifications, and the condition of coincidence of the phase velocities indicated leads to the condition of parametric amplification (III.51).

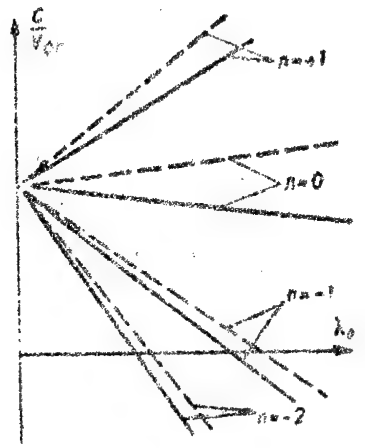

Fig. 18.

The fruitfulness of the method of examining coupled waves consists not only in explaining from a single viewpoint the work of EWT, tube with periodic change of wave resistance, but also explaining other super high frequency devices as well, examination of which is beyond the framework of this survey (traveling wave tube,revertive wave tube;isotron, tube with resistive walls and others).

The method of coupled waves makes it possible to indicate new perspective circuits of amplifiers and generators [8]. A two-beam tube of revertive wave can, for example, be realized by creating the periodic coupling of counter electron streams as is shown in Fig. 19 a,b. In Fig.19a the periodic coupling is achieved by means of slots in an electrostatic screen. In Fig.19b

this is accomplished by means of a zigzag trajectory of beams (focusing of the "slalom" type).

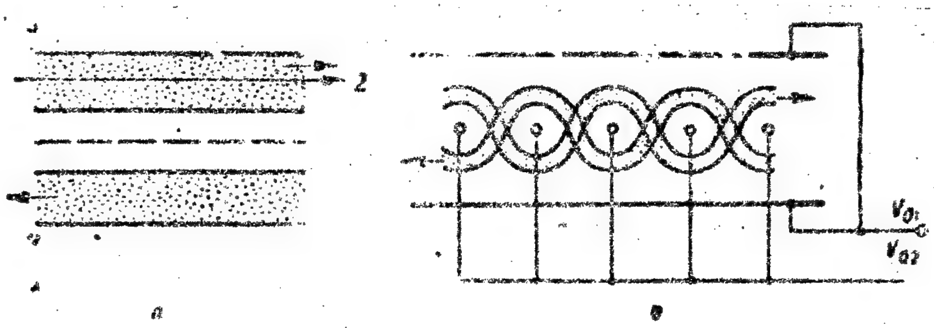

Fig. 19.

The dispersion diagram of the two-beam revertive wave tube shown in Fig. 19a, is given in Fig.20. At wave length λ_{01} the phase velocity of the slow wave of the space charge in beam 1 coincides with the phase velocity of the first revertive harmonic of the periodic beam. With sufficient length of the system and currents of the beams such a device will generate at wave length λ_{01}.

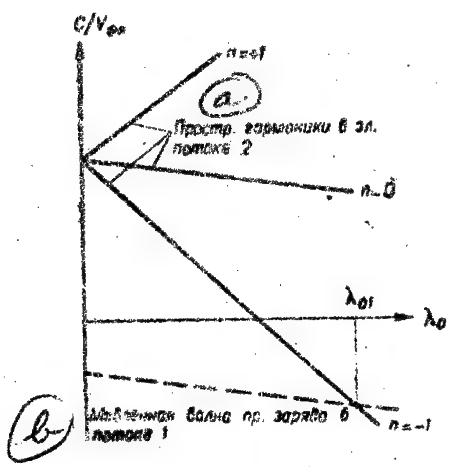

Fig.20.

a- space harmonic in electron stream 2

b - slow wave of space charge in stream 1

The approach examined makes it possible to predict and explain the effect of the electron stream's interaction with nonretarded electromagnetic waves, since from Fig.18 it is evident that the phase velocities of space harmonics with negative indices can be as large as one wants. The possibility of the interaction of the electron stream with a nonretarded electromagnetic wave was pointed out for the first time in the works [100,101]; after that this problem was investigated in [102,103] and super high frequency generators with nonretarded wave were achieved [104,105].

The described method can be used in principle also for explaining the work of super high frequency devices with zigzag trajectory of electrons (the strophotron - [106 to 110] and the "meandrous" type tube - [111]. The method developed in the works [102 to 105] can also be used for description of these devices.

IV. Noise Waves of the Space Charge

Noises in electron streams represent disorderly, chaotic variation in the time of electron stream characteristics, for example, the currents and velocities of

electrons, near their mean value.

Such fluctuation processes are characterized by a certain magnitude $X(t)$ of disorderly variation in time, which represents an instantaneous value of the fluctuations. Since the mean value of $X(t)$ of fluctuation for a sufficiently large segment of time is equal to zero, its mean quadratic value $\overline{X^{2t}}$ usually characterizes the fluctuation magnitude. In principle the fluctuation $X(t)$ can be represented by the Fourier integral, i.e. by a totality of harmonic processes, the frequency of which forms a continuous series of values from 0 to ∞:

$$X(t)=\int_{-\infty}^{\infty} A(f)\cos 2\pi f t\, df. \qquad \text{(IV.1)}$$

Here, the factor $A(f)$ represents the amplitude spectrum of fluctuations. For the mean quadratic magnitude occurs the correlation:

$$\overline{X^{2T_H}}=\int_{0}^{\infty} w(f)\, df, \qquad \text{(IV.2)}$$

in which

$$w(f)=\frac{8\pi^2}{T_H} A(f) A^*(f): \qquad \text{(IV.3)}$$

T_H is the time of observation, $w(f)$ is called the spectral density of fluctuation.

The dependence of the successive values of fluctuation on the preceding values is called autocorrelation.

If autocorrelation is absent, the spectrum of fluctuations has a constant amplitude in an infinite range of frequencies. If two different fluctuations are examined, then the dependence of the successive values of one fluctuation on the preceding values of the other fluctuation is called cross correlation. Two independent fluctuations do not interfere, but their mean quadratic values are added.

In the electron stream exist fluctuations of current and velocity of electrons, determined by the static character of the emission of electrons from the cathode. From the cathode in every small interval of time emerges a certain number of electrons distributed in velocities according to Maxwell's law. The quantity of emitted electrons, however, fluctuates disorderly near the mean value, causing fluctuation of the mean current. Further, the number of emitted electrons varies disorderly in each interval of velocities from v_0 to $v_0 + dv_0$. This causes a disorderly distortion of the velocity distribution curve, i.e. disorderly change of the mean velocities of electrons. Fluctuations in the velocities of electrons thus arise.

The fluctuations of velocity and current can be represented in the form of a spectrum of oscillations according to (IV.1) — (IV.3). It is evident that each

such oscillation will be propagated in wave form along the electron stream and noise waves of the space charge will arise. Although by virtue of the absence of autocorrelation the frequency range of the spectrum of current and velocity fluctuations is infinite, usually of interest are the noises in the narrow frequency band in which the electronic device functions. In the limit this will be one fixed frequency, and then the picture of noise waves is formed of two space charge waves. Each wave is analogous to the sum of the slow and fast waves examined earlier, but one wave occurs from fluctuations of mean velocity at the cathode, while the other is caused by fluctuations of current at the cathode.

It is convenient to conduct an investigation of space charge noise waves in the example of the noises in an electron gun (Fig. 21). The cathode is here arranged in the plane K; m is the plane of minimum potential, α is the plane in which $U_0 = 1$ to 2 volts and single velocity description of the electron stream becomes possible; A_1, A_2 and A_3 are the first, second and third anodes, A_3 to A_4 is the drift space.

The events in the section from the cathode to plane α set the initial conditions for the space charge noise waves in the area $\alpha - A_4$. The conclusions of sections II.1 and III.4 are applicable to the electron

stream in the area $\alpha - A_4$. In the segment $\alpha - A_3$ the noise waves are described by equations of the (III.27) type and in the drift space $A_3 - A_4$ by equations of the (III.38) type. From (III.38), it is possible to conclude that the expression for the mean square of the noise current in both waves must have the form:

$$\overline{I_i^{2t}}(z) = K \sin^2(\beta_s z + \varphi_1);$$
$$\overline{I_v^{2t}}(z) = L \sin^2(\beta_s z + \varphi_2). \qquad \text{(IV.4)}$$

Here the index i refers to the wave excited by fluctuations of current; index v to the wave excited by the fluctuations of velocity. The factors K and L depend on the character of the stream transformation in the area $\alpha - A_3$, on initial conditions in plane α, on wave resistance of the stream in the drift space W. In the general case $\varphi_1 \neq \varphi_2$, i.e. current nodes I_i^{2t} and I_v^{2t} do not coincide. Since the fluctuations of current and velocity occur independently, then

$$\overline{I^{2t}}(z) = \overline{I_i^{2t}}(z) + \overline{I_v^{2t}}(z). \qquad \text{(IV.5)}$$

Substituting (IV.4) in (IV.5) and making the transformation, one can derive:

$$\overline{I^{2t}}(z) = \frac{K+L}{2} - \sqrt{\left(\frac{K+L}{2}\right)^2 - KL\sin^2(\varphi_1 - \varphi_2)\cos(2\beta_s z + \psi)}, \qquad \text{(IV.6)}$$

in which

$$\operatorname{tg}\psi = -\frac{K\sin 2\varphi_1 + L\sin 2\varphi_2}{K\sin 2\varphi_1 + L\cos 2\varphi_2}. \qquad \text{(IV.7)}$$

The sense of formulas (IV.6) and (IV.7) consists in the point that the intensity of noises along the drift tube varies periodically, with a period depending on the plasma frequency. The depth of noise minimums and their position relative to the cathode depend on the stream transformation in the area $\alpha - A_3$ (geometry of the gun, distribution of potentials in the gun electrodes), on the initial conditions in plane α and the wave resistance of the stream W.

These conclusions based on the idea of the wave propagation of noises in the electron stream are well confirmed by experiment [112 - 115]. Investigated in work [112] was the distribution of noise intensity along the electron stream at a frequency of 4200 Mc by means of a resonator moved along the stream. The experiments confirmed the periodic variation of the intensity of noises along the drift space (Fig.22).

Investigation of the dependence of the noise factor of TWT on gun distance, the beginning of the spiral [115] confirmed the periodic distribution of noises (Fig.23). Moreover, in accordance with (IV.6) and (IV.7) the variation of gun electrode potentials causes displacement of noise minimums and variation of the absolute noise magnitude (the various curves in Fig. 23 are plotted for different distributions of potentials in the gun).

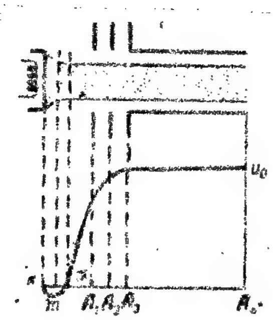

Fig.21

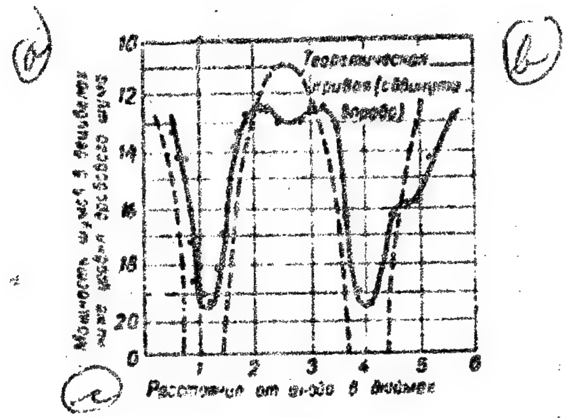

Fig.22

a - volume of noises in decibels below the level of fluctuation noise

b.- theoretical curve shifted to the right

c - distance from anode in inches

Both works [112,115] confirm also that the intensity of noises in the minimum never falls to zero.

From (IV.6) the interesting result can be derived:

$$\overline{I^2}_{max} \cdot \overline{I^2}_{min} = K L \sin^2 (\varphi_1 - \varphi_2). \qquad \text{(IV.8)}$$

In the works [116 — 119], this important formula of the theory of noises is developed in more general form.

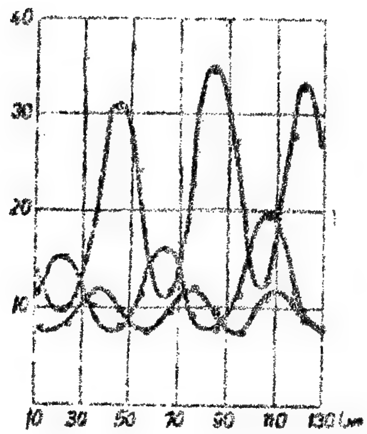

Fig.23.

and it is proved that the product $\overline{I}_{max}^2, \overline{I}_{min}^2$ with an accuracy reaching multiplier W^2 is determined by the values I^2, v^2 in the input plane and remains constant along the stream. This statement is right for the stream described by equations of the (III.27) type so that it is not possible without losses to reduce the value I_{max}^2 and simultaneously I_{min}^2 by means of a linear passive quadripole.

A considerable number of works [4,82,90,116 - 133] are devoted to the study of noises in the electron stream on the assumption that single velocity approximation and linear transformations of the (III.27) and (III.28) type have force. In the works [127 - 129] it is proposed that jumps of potential be utilized to reduce the space charge noise wave (see sections III.4 and III.5). The reduction

of noises in such a way is, however, limited, since in the waves components shifted by 90° in phase are present, therefore the weakening of one component is accompanied by amplification of the other [120]. In other works (for example, [130]), it is proposed that the accelerating range of the exponential course of wave resistance be utilized for reduction of noises. It is noted in the work [132] that with setting of the TWT input spiral in the noise wave minimum should be attained a reduction namely of $\overline{I}_{min}^2$ and the possibilities of realizing this are investigated. A number of authors [116,117,121 - 124] have also worked on the improvement of the noise characteristics of electron beam devices. In article [94] are discussed certain results of work in the reduction of noises in the traveling wave tube achieved in various countries.

It should be observed, however, that all the above-cited correlations without definition of the initial conditions in plane α have a formal character, not allowing for calculation of concrete noise values in these or those conditions. These conditions can be considered either formally [134 - 136], or in research of the physics of processes near the cathode, in the minimum of potential and in the mathematical representations of these processes.

It has been established at the present time that

the fluctuations of current at the cathode $\overline{I_k^2}$ are described by the Schottky formula for the shot effect:

$$\overline{I_k^2} = 2\,e\,I_{os}\,\Delta f. \qquad \text{(IV.9)}$$

in which $\overline{I_{os}}$ is the current of saturation. Fluctuations of mean velocity at the cathode, on the assumption of the Maxwell velocity distribution of electrons and the independence of fluctuations in each interval of velocities v_0, $v_0 + dv_0$ are described by the following formula:

$$\overline{v_k^2} = (4-\pi)\,\frac{e}{m}\,\frac{k\,T_k}{I_{os}}\,\Delta f. \qquad \text{(IV.10)}$$

Here k is the Boltzmann constant, T_k the cathode's absolute temperature.

At the potential minimum, however, the current fluctuations reduce substantially the space charge at the cathode. This takes place as follows: with increase in the number of electrons emitted by the cathode, the space charge at the cathode is increased, the potential reduced, and a lesser number of electrons can now overcome the potential minimum. Automatic self-suppression of current fluctuations occurs, and the current fluctuations at the potential minimum are found less than the full shot effect at the cathode (IV.9). At low frequencies this is taken

into account [137] by the multiplier $\Gamma_m^2 < 1$ in the formula (IV.9), so that for current fluctuations at the potential minimum we have:

$$\overline{I_m^2} = \Gamma_m^2 \, 2 e I_0 \Delta f, \qquad \text{(IV.11)}$$

in which I_0 is the anode current. In the same work [137], for velocity fluctuations at the potential minimum the formula developed is:

$$\overline{v_m^2} = (4 - \pi) \frac{e}{m} \frac{k T_x}{I_0} \Delta f. \qquad \text{(IV.12)}$$

With respect to self-suppression of current fluctuations at the super high frequencies when transit phenomena have effect, in the cathode space, a potential minimum, some authors [116,118,120,121,123] presured that there is no self-suppression and $\Gamma_m^2 \approx 1$, other authors [126,127,128,138] considered the self-suppression complete and $\overline{I}_m^2 = 0$. The works [115,139,140], however, demonstrated that not one of these extreme viewpoints is true. Developed in work [139] is the expression for $\Gamma_m^2 < 1$, but without taking velocity distribution of electrons into account. In the work [140] the processes of electron emission in super high frequencies were modelled by means of an electronic computer. In consequence, the formulas (IV.11) and (IV.12) were confirmed, and for Γ_m^2 values

were derived that depend on frequency and are given in Fig.24.

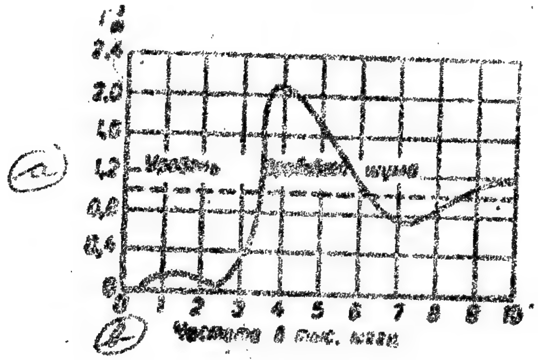

Fig. 24.

a - level of fluctuation noise

b - frequency in thousands of Mc

Fig.25 illustrates the experimental confirmation of suppression of noises at super high frequency by the space charge at the cathode [115]. Given in this drawing is the dependence of the traveling wave tube's noise factor on the potential of the drift space at various filament currents. The rise of the curve number corresponds to the change of cathode working conditions from saturation to complete space charge.

The behaviour of noises in the $M\alpha$ area was investigated in the works [141,142]. In the area examined the velocity straggling we compare with the value of the mean velocity, and the stream is essentially multivelocity. It is confirmed that in plane Ø a noise minimum three to

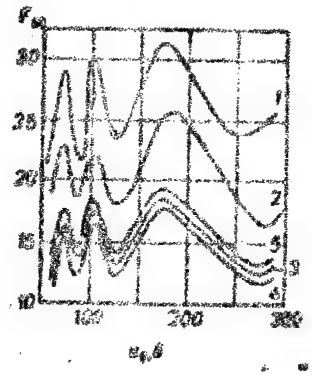

Fig.25.

four decibels below the fluctuation noise can be obtained. The method used in [141,142], however, requires in the plane of the potential minimum definition of the value of fluctuations at each interval of velocities $v_0, v_0 + dv_0$. Works in noises at the potential minimum do not yield such data; therefore, a theory describing events in the Kα section as a whole does not yet exist and various authors use various initial conditions in plane α.

The effort to get a more correct quantitative description of noises (in particular, to calculate accurately the position of the first minimum of noises and the absolute magnitude of noises) has led to the idea that the point character of fluctuations should be taken into account, the nonuniformity of emission characteristics at the cathode surface [115,143]. Consideration of these factors shows that for reduction of noises, uniformity of emis-

sion characteristics at the cathode surface has to be achieved and the mixing prevented of electron streams from various sections of the cathode. The latter is attained by placing the cathode directly in a strong magnetic field, in which the trajectories of electrons are not intersected. Uniformity of emission characteristics is improved with use of a small oxide grain, with creation of a smooth emitting surface, elimination of marginal emission, the use of cathodes with low coating resistance and operation with low current densities.

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Effect of Positive Ions on Formation of Intensive Electron Beams in High Vacuum Conditions

2

by V.P.Taranenko

A critical survey is made of research findings in the problem of the effect positive ions have on the focusing of extended electron beams in electrical and magnetic fields under high vacuum.

Introduction

The problem of neutralization of the space volume charge of electrons in a beam by a positive charge formed with ions has for a long time already and repeatedly been a subject of experimental and theoretical research.

It is known that the electron beam passing in the transit channel of the electron tube, under the pressure of residual gasses 10^{-2} - 10^{-3} mm of mercury column, is focused and assumes the form of a thread ("cord-like beam") or standing wave ("nodular beam"). The focusing of the beam is a consequence of the ionization of residual gasses and the formation of a positive ionic charge in the path of the electrons. This phenomenon which has been given the name of "gas concentration" , has found detailed elucidation in the theoretical investigations of Scherzer

and others [1], Frenkel' and Bobkovskiy [2], Bredov [4], Davydov and Braginskiy [3].

The neutralization of the volume charge in a two-electrode system was examined in certain works, for example, Morgulis [5], Ptitsyn and Tsukerman [6], Gurtovoy and Kovalenko [7].

Neutralization by a positive ionic charge makes it possible to increase the maximum density of the current which can pass through a preset system of electrodes (works of Pierce [8], Müller-Lübeck [9]. A number of the above-mentioned works have been commented on briefly in the survey article of Gabovich [10] on the problem of the propagation of beams of charged particles.

In connection with the fact that, from considerations of preserving the cathode and high electrical durability, the operation of many electrovacuum devices occurs under more rigid vacuum (order of 10^{-6} - 10^{-7} mm of mercury column), the problem of neutralization of a space charge by positive ions in the range of pressures indicated is of interest.

Owing to the development in recent years of the technique of forming and focusing intensive electron beams finding wide application in super high frequency electron beam devices, and others, a series of investigations have appeared that are devoted to the neutralization of the

electron charge by positive ions of residual gases in conditions of high vacuum (to 10^{-7} mm of mercury column) [11 - 15]. It is found that the ionic background influences the focusing of the electron beam as well as the working processes that occur in the electron beam device (for example, the grouping of electrons and others) [11]. Investigation of this influence merits serious attention.

The development of electronoptical systems which secure the accumulation of positive ions in equipotential transit channel of the electron beam device, make it possible to increase the effectiveness of the focusing systems.

In this article a brief critical survey is made of the principal findings of investigations in recent years on the problem of the effect positive ions have on the focusing of extended electron beams in electrical and magnetic fields under high vacuum.

The problem of oscillations in the beam because of the presence of ions merits separate study and is not examined in this work.

Elementary Theory of Ion Accumulation in the Beam

Even under extremely low pressures (order of 10^{-7} mm of mercury column), an electron beam of great

density forms ions. Under the influence of the forces of the space charge's electrical field, the ions travel to the beam axis (Fig. 1,a). But this field forces slow electrons, formed in the process of ionization, to travel from the beam to the walls of the transit tube.

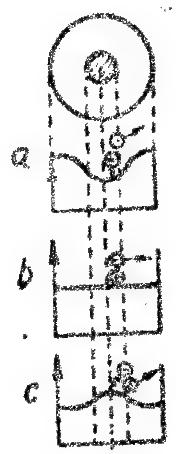


Fig 1.- Distribution of potential in the cross section of the metal cylinder with the beam.

If at the edge of the equipotential tube, a potential gradient carrying off ions is absent, then the ions accumlating at the beam axis form a charge that neutralizes the negative space charge of electrons. The velocity of ion formation in one centimeter of beam length is equal to [12]:

$$\left(\frac{d N_p}{d t}\right)_1 = \pi r^2 \varepsilon n_e v_e p \, . \qquad (1)$$

where r is the beam radius; n_e and v_e are the concentration

and velocity of electrons; ε is the specific ionization; p is the pressure of residual gases.

It can be assumed that the captured ions form ionic gas. The density distribution of ionic gas is then defined by the Boltzmann formula.

The velocity of loss of electrons, on account of ions departing to the wall, is defined by the expression [12]:

$$\left(\frac{dN_p}{dt}\right)_2 = 2\pi R n_{p0} \left(\frac{KT_p}{2\pi M}\right)^{\frac{1}{2}} e^{\frac{e\Delta U}{KT_p}}, \qquad (2)$$

in which R is the tube radius; n_{p0} is the concentration of ions at the axis; ΔU is the difference of potentials of the axis and wall of the transit tube; T_p is the "temperature" of the ionic gas in the trap.

With equilibrium from (1) and (2) we find

$$p = \frac{R n_{p0}}{\sqrt{\pi}\, r^2 \varepsilon n_e}\left(\frac{m U_p}{M U_e}\right)^{\frac{1}{2}} e^{\frac{\Delta U}{U_p}}. \qquad (3)$$

Here U_p is the temperature of the ionic gas in equivalent volts, U_e is the energy of the beam's electrons. Assuming $\Delta U = 0$, the magnitude can be estimated of the pressure at which full neutralization of the space charge will occur (Fig 1,b). If the pressure is greater than the magnitude determined from (3), the velocity of ion

formation exceeds the velocity of their leakage and ΔU can change its sign. The potential hollow becomes a potential hump (Fig. 1, c).

This is the case of the already mentioned "gas concentration" of the beam under pressures of the order of $10^{-2} - 10^{-3}$ mm of mercury column, when ion accumulation occurs even in the presence of considerable potential gradients that carry off positive ions.

Under lower pressures, if it be assumed that only a few ions are lost, a sufficient number of positive ions can accumulate finally at the axis of the transit tube and the electron charge be fully neutralized.

Several reasons for the loss of ions exist:

(1) The recombination of ions in neutral molecules. Under the pressure of 10^{-7} mm of mercury column the velocity of ionization exceeds considerably the velocity of recombination. The losses of ions on account of recombination can, therefore, be disregarded.

(2) The thermic energy of ions determined by the value KT (practically of the order of 0.025 v). This magnitude is considerably less than the potential drop in the beam cross section and it can be disregarded.

(3) The impact energy acquired by an ion on collision with an electron. The magnitude of this energy is

small as compared with the energy determined by the potential drop in the beam.

(4) The leakage of ions to the insulator arranged in the transit space and negatively charged by the electrons that have settled on it, is an extremely serious cause. The electron beam can, however, be surrounded by a metal wall and in this way be protected from the effect indicated.

(5) The accelerating field from the cathode-anode zone, penetrating to the transit tube through the opening at the anode, draws ions to the cathode. The travel of ions at the beam beginning form a zone with low potential to which ions flow from neighboring parts of the beam, which are far in the transit tube. The effect of the "draft" field is in this way felt at considerable distances along the beam. This is the main reason for the loss of ions, and also the mechanism of their travel observed for the first time by Field, Spangenberg and Helm [14].

Let us dwell briefly on the theory of the travel and accumulation of ions in the beam. The theory is limited by the following assumptions: (1) all ions have the same charge and mass; (2) plasma oscillations are absent; (3) the slow electrons appearing in the process of ionization, swiftly recede and do not influence the magnitude

of the space charge; (4) the initial velocities of the ions (after their appearance) can be disregarded; (5) the average magnitude of the potential in the beam is proportional to the linear density of the electron charge; (6) at the entrance to a sharply breaking ion-trapping field, the beam is parallel; (7) an accelerating field is absent in the zone of the transit tube.

The geometry of the system being examined is represented in Fig. 2.

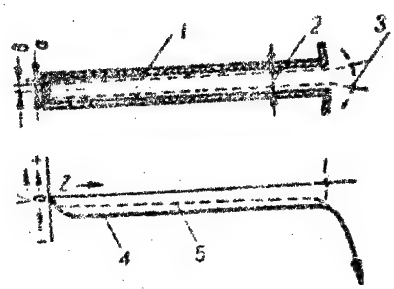


Fig. 2. Diagram of potential distribution along the axis of electronoptical system: 1 - transit tube; 2 - electron beam; 3 - cathode; 4- potential at axis without ions; 5 - potential at axis with partial neutralization

The potential at the beam axis V_0 is equal to:

$$V_0 = \frac{\sigma}{4\pi\varepsilon_0}\left(1 + 2\ln\frac{a}{b}\right).$$

in which σ is the volume density of the charge in coul/m;

a is the transit tube radius; b is the beam radius; ε_0 is the dielectric constant of the vacuum.

The potential at the beam edge V_b equals:

$$V_b = \frac{\sigma}{4\pi\varepsilon_0}\left(2 \ln \frac{a}{b}\right).$$

All ions are formed from the right of point $z = 0$ and are drawn to the right. If it is assumed that the ions are formed with constant velocity G_i a/M, the ion charge density will be determined by the integral in the zone from 0 to z:

$$\sigma_i(z) = \int_0^z \frac{G_i\,dx}{\left\{2\frac{e}{M}[V(x) - V(z)]\right\}^{\frac{1}{2}}}; \qquad (4)$$

x is the space variable with integration;

e/M is the ratio of the charge to the mass of ions.

Equation (4) can be rewritten in the form:

$$\sigma_i(z) = \frac{G_i}{\left(2\frac{e}{M}\lambda\right)^{\frac{1}{2}}}\int_0^z \frac{dx}{[\sigma_i(x) - \sigma_i(z)]^{\frac{1}{2}}}; \qquad \lambda = \frac{\frac{1}{2} + 2\ln\frac{a}{b}}{4\pi\varepsilon_0}.$$

The solution of this equation is given in [14]:

$$A = \frac{3\pi G_i z}{2[\sigma_i(0)]^{\frac{3}{2}}\left(2\frac{e}{M}\lambda\right)^{\frac{1}{2}}} = \left(1 + 2\frac{\sigma_i(z)}{\sigma_i(0)}\right)\left(1 - \frac{\sigma_i(z)}{\sigma_i(0)}\right)^{\frac{1}{2}}. \qquad (5)$$

Shown in Fig.3 is the dependence $\frac{\sigma_i(z)}{\sigma_i(0)}$, as a function of the left part of (5). The right part of the

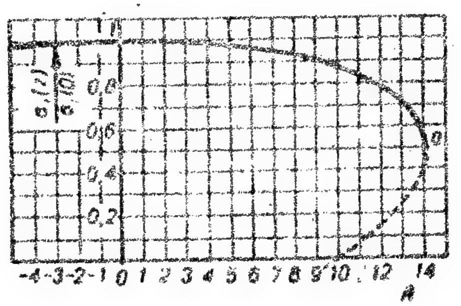


Fig.3. Dependence of relative ion density on system parameters in accordance with (5). The curve is symmetrical relative to the axis of ordinates.

curve corresponds to the zone of positive z. Both parts are applicable, if the ions are drawn from two sides. (In this case $Z = 0$ in the center of the tube).

At the point of the bend where $\frac{\sigma_i(z)}{\sigma_i(0)} = \frac{1}{2}$, the left part of (5) is equal to $\sqrt{2}$.

The potential gradient, whose value is determined by the slope of the tangent at each point of the curve, is in the given point equal to infinity. (Inasmuch as a beam with uniform density is being examined, it can be assumed that the potential will be proportional to the charge density. In this case the tangent to the curve of charge density distribution will determine the potential gradient). In the real system a high terminal gradient

of the draft field exists at the entrance to the transit tube, where the process of drawing ions to the cathode begins, and the ion density is appreciably changed according to the curve from the point of the tangent with slope m (m is the gradient at the opening) to the maximal value at point $z = 0$. According to the foregoing, point a, at which the ion density of the charge is least, is at the entrance to the transit tube, where $z = l$ (Fig.3).

The greatest density of the ionic charge $\sigma_i(0)$ can be determined from the correlation:

$$\frac{3\pi G_i l}{2\left\{2\frac{e}{M}\lambda[\sigma_i(0)]^{\frac{3}{2}}\right\}^{\frac{1}{2}}} = \sqrt{2}, \qquad (6)$$

in which λ and l are determined by the system geometry.

The value G_i (in amperes per meter) can be calculated according to the given ionization probability [15,16]:

$$G_i = 100\, i_e P_i p \;\; a/m$$

(i_e is the electron current, p the pressure in mm of mercury column). So, for example, for residual gases (N_2, O_2, CO) in electron-beam devices the probable number (P_i) of ionization by collision on electrons in 1 cm of length with 1 mm of mercury column will be 10 in 100 v, 4 in 1000 v and 2.8 in 2000 v. The ionization probability at

lower pressures is proportionally less.

Hines and others cite data on correlations of the maximal density of the ionic charge to the electronic, calculated for certain types of tubes with traveling wave, that use a beam with 37.5 ma current at 2000 v velocity, passing inside a spiral of 0.080 inches inside diameter / 15 /: $G_i = 11 \times 10^{-6}$ a/m at 10^{-6} mm of mercury column; $G_i = 11 \times 10^{-7}$ a/m at 10^{-7} mm of mercury column.

If the beam diameter be assumed equal to half the internal diameter of the spiral and the length $l = 17$ cm

$\sigma_i(0)/\sigma_e = 1$ at $3 \cdot 10^{-6}$ mm of mercury column

$\sigma_i(0)/\sigma_e = 0.5$ at $1 \cdot 10^{-6}$ " " "

$\sigma_i(0)/\sigma_e = 0.1$ " $1 \cdot 10^{-7}$ " " "

$\sigma_i(0)\sigma_e = 0.02$ " $1 \cdot 10^{-8}$ " " "

At pressure above $3 \cdot 10^{-6}$ mm of mercury column, the magnitude of ionic charge density is more than electronic density. In this case the surplus of ions is removed by the arisen field to the spiral. With the preset system geometry and constant voltage and pressure, the beam current growth will reduce the ratio σ_i/σ_e (σ_e is the electron charge density).

Field [14] presents universal curves of the density of ions (Fig.4)for various pressures with constant gradient at the entrance opening (determined by external

factors). The beam velocity corresponds to 6000 v. If, after having begun with a definite gradient value, the curve of ion density reaches the value of the electron density magnitude at a considerable distance from the collector, the density of ions is no longer increased and remains equal to the electronic in the entire distance remaining to the collector.

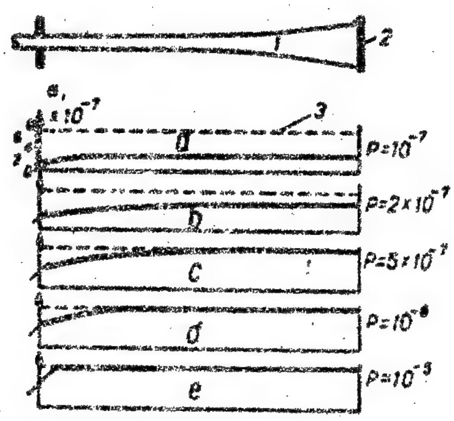


Fig.4. Distribution of Density of ions in the system length (density of ions 6 ; expressed in the number of ions per centimeter): 1 - electron beam; 2 - collector; 3 - curve of the density of electrons.

Of interest is the magnitude of the distance from the collector to the point at which the density of ions reaches the density of electrons (Fig.4,c). This value can be determined from (6).

Ion Density in a Beam of Variable Diameter

The electron beam devices that use extended

electron beams, usually operate with the application of magnetic focusing. In the majority of cases, the Brillouin stream is used to obtain a beam with invariable diameter, since at the same time the least magnitude of focusing field is required. In practice it is difficult to fulfill the conditions of Brillouin especially at the entrance to the magnetic field. For good origin of the beam in the transit channel, it is necessary to work with a magnetic field of somewhat larger magnitude than in Brillouin [15,16,17]. In this case the beam assumes a nodular form and the potential distribution in the beam will be non-homogeneous with a series of isolated potential wells ("pits" in the narrow places of the beam). If the beam diameter varies two-fold then the potential at the axis in the beam's narrow part will be several scores of volts more negative than at the axis in the broad part [15]. The potential "pits" are traps for ions which accumulating in considerable quantity in the depth of the "pits" equalize the potential profile (Fig.5). The surplus of ions above that which is essential for complete neutralization of the potential "pit", can be drawn along the axis or recombined. The presence of ions at the beam's narrow spots can change the trajectories of electrons, and it can be assumed, that in conditions of a finally

established equilibrium in the presence of ions, the fluctuations of beam diameter will be of greater magnitude than in the absence of ions. The degree of neutralization derived is at the same time somewhat greater than according to the theory of Field. This must be kept in mind when designing electronoptical systems for devices operating with intensive beams in conditions of comparatively "poor" vacuum (order of 3 to $5 \cdot 10^{-6}$ mm of mercury column).

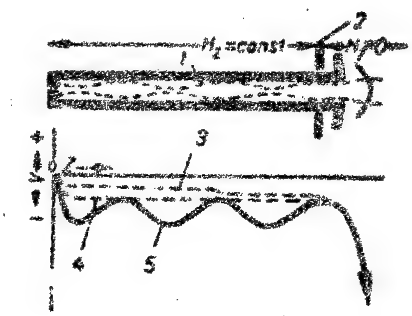


Fig.5. Distribution of potential in length of beam focused by magnetic field: 1 - beam; 2 - magnetic screen; 3 - potential at axis with $\rho = \sim 10^{-6}$ mm of mercury column; 4 - potential at the axis with $\rho = \sim 10^{-8}$ mm of mercury column; 5 - potential at axis in the absence of ions.

Experimental Investigation of Neutralization of Space Charge Field

One of the ways of investigating the theory of ion accumulation in the transit channel is the measurement of the degree of neutralization with positive charges of the electron beam in the function of pressure. The degree of

neutralization can be determined by dispersion of beam. Such investigations were made for the first time by Field and others [14]. The beam diameter in the investigations was determined by heating the metal target (inasmuch as the beam diameter in the experimental investigations was of the order of 1 inch, the accuracy of such measurements for qualitative explanation of results can be considered sufficient).

The results of the experiment are presented in Fig.6,a. The parameter is the energy of electrons moving in the equipotential transit space. The experimental data are in satisfactory accord with the calculated (Fig.6,b). Electron beams with low velocity are appreciably expanded at a vacuum higher than high-voltage, their expansion growing in lesser degree than the pressure falls and, moreover, they possess the greatest terminal dispersion.

The foregoing findings relate to the case when no measures of any kind were taken for accumulation of ions in the system's transit channel. Besides the electrical field penetrates through the opening in the anode plate to the equipotential space of the transit tube and draws ions intensively toward the cathode. (If the diaphragm-cylinder system is used, the penetrating field will be of the order of 0.1 % of the maximal field in the accelerat-

-ing zone).

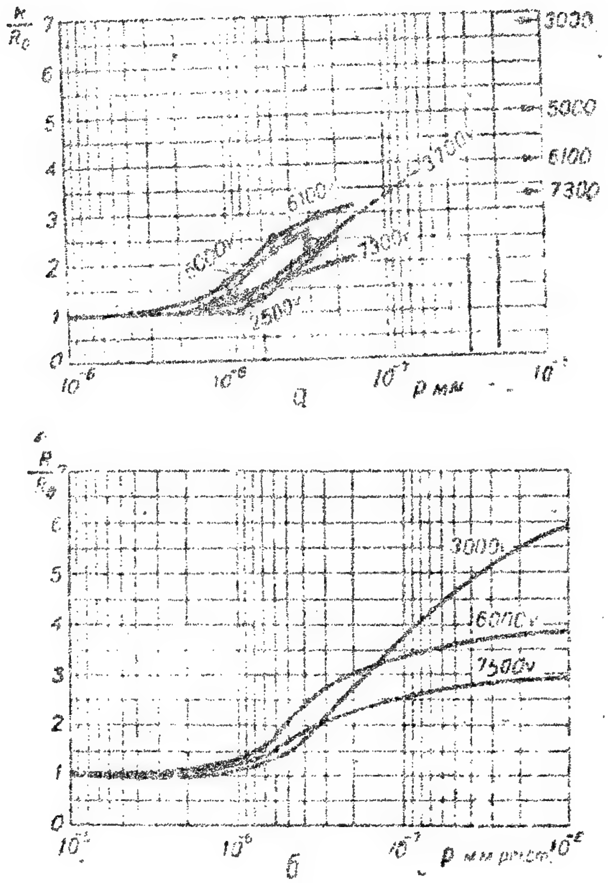


Fig.6. Dependence of Beam Dispersion on pressure: $J = 50$ ma; $j = 0.1$ a/cm^2; $l = 36$ cm; *a* -experimental, *b* theoretical.

The imposition of a potential opposite in sign to the zone of the opening excludes the axial drawing of ions to the cathode. The principle of the ion trap (Fig.7) is also based on this. The potential at the axis of the system in the neutralized beam will be somewhat lower than the potential of the transit tube V_0 by a magnitude depending on the beam parameters. If the beam retains ions from the

right of cross section AA, the potential at the axis from the right of AA approximates the potential V_0 by a value depending on the degree of neutralization. In case of full neutralization the potential at the axis reaches the value V_0. This means, that for effective accumulation of ions from the right of AA, it is essential to have a voltage somewhat higher than V_0 in the trap. According to Field's findings ΔV must by a few volts in all exceed the value of potential sagging. (If sagging is of the order of 10 v, ΔV is sufficient to have a value of 15 v).

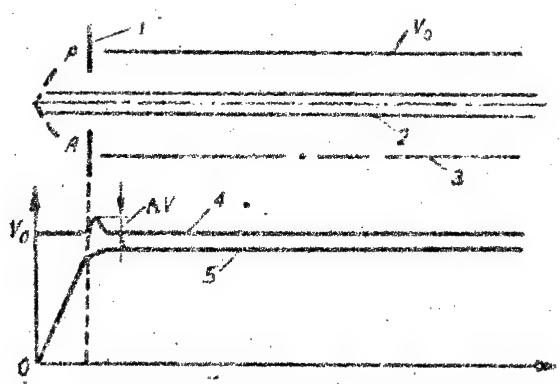


Fig.7. Diagram of the action of an ion trap: 1 - electrode of trap of ions; 2 - electron beam; 3 - transit tube; 4 - potential curve at full neutralization; 5 - potential curve in beam (at the axis) without ions.

The following data from the experiments of Field are interesting. A beam of 130 ma at 7300 v was formed. At a distance of 36 cm the beam diverged in two. The imposition of 15 v on the ionic trap completely eliminated

the beam expansion.

The problem of the neutralization of a magnetically focused electron beam with positive ions was investigated experimentally by Hines and others [15] in one of the models of traveling wave amplifier. The modified traveling wave amplifier tube (Fig.8) was equipped with an additional collector of ions, arranged concentrically with a hollow electron collector. The constant potentials at the tube electrodes are so selected that the positive ions, which arise in the zone of the spiral, can be drawn to the ion collector. The investigations were made in impulse conditions with pulse duration of the order of 700 msec and repetition frequency of 60 per/sec. According to the findings [12], the pulse duration is fully adequate for accumulation of an ionic charge. The method of Hines differed from the method of Field and others. In the process of experimental tests the form of the current at the ion collector was investigated. It was found that several microseconds pass before the ion current in the collector reaches its balanced value. The positive charge which cannot at once reach the ion collector, but which nevertheless begins to form as soon as the electron current appears, represents ions remaining somewhere in the zone of the spiral. It can be assumed that the integration in time of ion current shortages to the balanced value

yields a purely ionic charge residual in the beam (Fig. 9)

$$Q_i = \int_0^{\tau} [i_{i\,(max)} - i_{i\,(t)}]\, d\,t\,,$$

in which Q_i is the charge in coulombs; $i_{i\,max}$ is the balanced value of ion current in amperes; $i_{i\,(t)}$ is the instantaneous value of ion current in amperes; τ is the time in seconds required for the ion current to reach its balanced value. The full space charge in the electron beam in the zone of the tube spiral is expressed as

$$Q_e = \frac{i_e\, l}{(2\,\eta\, V)^{\frac{1}{2}}}\,,$$

where Q_e is the charge of the beam electrons in coulombs; i_e is the electronic current in amperes; V is the potential of the spiral in volts; l is the spiral length in meters

$$\eta = \frac{e}{m}\,.$$

The mean value of the degree of neutralization by positive ions in the zone of the tube spiral is defined by the ratio Q_i/Q_e.

During the experiments the beam was speeded up to a velocity of 1000 v, the spiral had a potential 50 v below the anode potential, and the electron collector potential was 100 v below the anode potential. During the

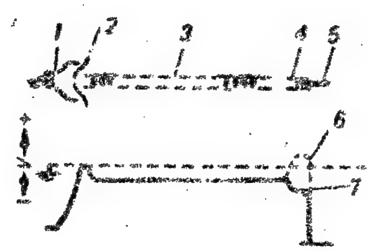


Fig. 8. Setup of the Hines experiment: 1) cathode; 2) anode; 3) spinal coil; 4) electron collector; 5) ion collector; 6) ionic trap; 7) ion extraction.

Fig.9. Curve of Ion Current
Growth.

experiment the pressure in the tube was changed by variation of the evacuation line resistance. Fig. 10 shows the degree of neutralization by positive ions in the function of pressure. Cited there also are the values of the maximal neutralization calculated according to Field's theory. The correspondence between them is satisfactory with small order of magnitude of pressure variation. The

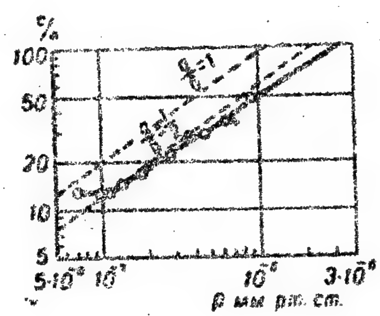


Fig.10. Dependence of neutralization on pressure (- - - - calculation according to Field, -.-.- Hines experiment).

authors (Hines and others) reached the conclusion that the theory of ion accumulation of Field and others is applicable to magnetically-focused beams when the beam

approximates a cylindrical form.

Ginzton and Wadia [13] carried out an experimental investigation of the possibility of applying an ion trap for the conditions of a beam characteristic for the usual klystrons and traveling wave amplifier tube. Gridless ion traps made in the form of a ring or diaphragm were investigated. The grid type traps were not applied because of the complexity of power dispersion by the grid. The attempts to use the trap described by Field in real electronoptical systems of klystrons and traveling wave amplifiers failed. Shown in Fig 11 is the circuit of the experimental investigations of the authors of study [13].

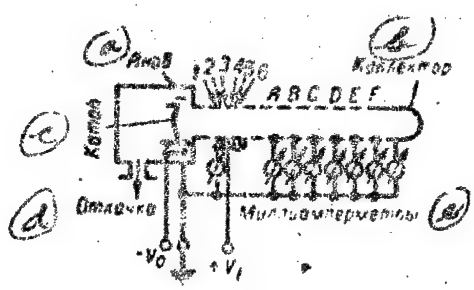
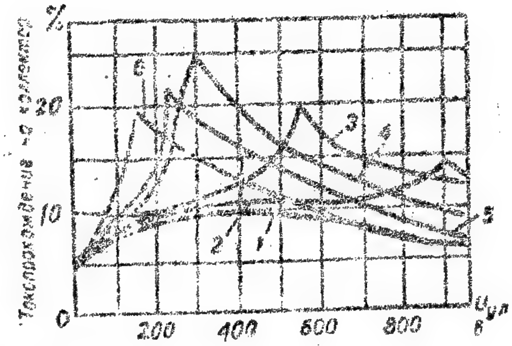


Fig.11. Circuit of Experiments of Ginzton and Wadia

a - anode
b - collector
c - cathode
d - evacuation
e - milliamperemeters.

Let us examine the curves they received of the dependence of the passage of current in the collector (Fig.12) on the function of the ion trap potential

for various (relative to the cathode) positions of the trap rings (the first ring is located closest to the cathode).



a- current passage in collector

Fig.12. Dependence of Current Passage in the collector on the potential U_{tr} in the trap rings (V_y = 200 v; p = $2.6 \cdot 10^{-7}$ mm of mercury column).

The greatest current passage (Fig 12) is observed in that case when a definite trapping voltage is applied to the fourth ring of the trap. Change in the magnitude and place of voltage application in the trap causes considerable reduction of current passage. (It should be observed that with the voltage in the trap selected by the authors, the effect of the electrostatic lens is felt, which is also the explanation of the course of the curves in Fig.11). The position of the trapping ring at which the greatest current passage is obtained (in the given case No 4) corresponds, the authors think, to the point of the beam crossover. With the greatest current circuit, the current in the collector reaches only 25 %.

These results differ from those received by Field and others.

The authors of study [13] are of the opinion that the idealized theory of Field can be applied for a thin beam with low conductivity ($I/U^{3/2}$). The main difficulty in designing ion traps consists in determining the electrical field in the zone of the trap. The potential distribution in the trapping zone is determined by three fields:(a) the field formed by the trap potential positive in relation to the transit tube; (b) the field of the space charge of beam electrons;(c) the field of the positive charge of ions detained in this zone.

With voltage present in the trap the distribution of potentials can be determined in an electrolytic bath. The effect of the action of the beam space charge is roughly estimated analytically or graphically. In consequence the ion trapping position can be determined of the equipotential surface having the potential of the transit tube. Shown in Fig.13 is the distribution of trapping equipotentials for three values of voltages in the trap for the beam with a velocity of 2000 v and conductivity of 1.07 to 10^{-6}, just filling the transit tube. In the first case (a) the voltage in the trap is sufficient for trapping ions and the beam can be fully neutralized from

the right of the trap. The crosshatched part of the

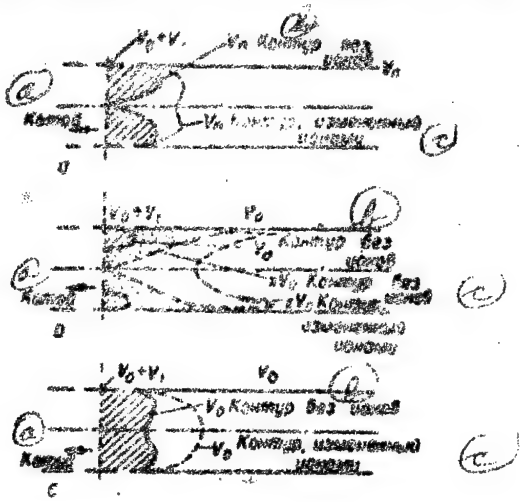


Fig.13. Distribution of trapping potentials.

a - cathode
b - circuit without ions
c - circuit changed by ions

diagram shows the zone in which the potential is higher than the potential in the trap (V_t); consequently, all the positive ions formed in this zone are driven back to the wall or flow to the zone with lower potential. The cross-hatched zone cannot, therefore, in any appreciable measure, neutralize its space charge. The space from the right is the zone completely surrounded by potential V_0. The positive ions that are in this zone, will remain here and neutralze the beam. As soon as neutralization begins V_0 equipotential is shifted to the right owing to the accumulation of positive charges and, naturally, the trapping zone migrates to the depth of the transit tube.

In the second case (b) the magnitude of the voltage in the trap is less than the minimal essential for accumulation. The space, crosshatched with lines, is the zone with potential higher than V_0 and, consequently, must be free of ions. The space in which the potential is lower than V_0 has direct connections with the low potential area near the cathode, to which the ions are continuously drawn. Some accumulation of ions can take place only inside the space surrounded by the circuit indicated by the dashed line in Fig 13,b. We denote the potential in this circuit χV_0 where $\chi < 1$. With the accumulation of positive charges the equipotential χV_0 will be shifted just as in the case (Fig.13,a) to the right. In this case neutralization can be considerable: first, the trapping zone is small and second the accumulation of ions takes place inside the circuit of a potential less than V_0. With a high potential in the trap (Fig.13,c) the trapping zone is removed far to the right, which increases considerably the length of the beam's non-neutralized part.

On the basis of the views cited above about the events taking place in the zone of the ion trap, Ginzton and Wadia examined the effect of current circuit through the zone neutralized by ions.

Electrons passing through this neutralized

equipotential space, preserve their velocity and initial travel direction. The slope of the trajectory of each electron at the entrance to the zone of ion accumulation is, therefore, a most important factor essentially determining the further behaviour of the beam. With the use of ion traps the best passage of current can be obtained either with a parallel beam or in that case if the trapping equipotential will coincide with the electron beam crossover. From here also originate the reasons for the complexity of applying ion traps in real conditions: (1) it is impossible to determine accurately the trapping equipotential; (2) in real conditions it is difficult to determine the position of the crossover, which can be changed with variation of the electron beam device's operating conditions. The latter also apparently explains the fact that the magnitude of limit currents in the presence of ions, according to experimental data of A.V.Golenberg [18], is close to that calculated according to formulas for a neutralized beam [19,20].

It is interesting to examine the effect of the migration of the trap electrode. With placement of the ring close to the cathode, the voltage required for the best passage of current, becomes higher, which is apparently to be explained by the point that the drawing field has stronger effect close to the cathode.

If the surface of accumulation is deepened in the zone where the beam diverges, the electrons will move with the same positive slope and only a small improvement of current circuit can be expected. If the trapping voltage is applied to the electrode close to the cathode, the beam will converge to the crossover and beyond again diverge. The position of the trapping ring, that will shift the surface of accumulation close to the crossover, will give the best results.

Conclusion

In conclusion the following can be observed:

The theory of Field and others [13] is applicable only in special cases of thin beams of low conductivity. The conditions of perfect accumulation can be fairly simply determined; they are not very readily realized, however, in gridless ion traps. Many difficulties are associated with the point that the electronoptical systems of devices are not designed from the viewpoint of the correct position of the ion trap. It is, therefore, impossible to get a configuration of trapping field such that not all the beam electrons enter it with zero slope of trajectory.

A series of experimental investigations have in recent years been made of the compensation of the electron

beam space charge [21,22]. One of the studies [21] is devoted to an experimental investigation of the influence positive ions have on the focusing of electron beams in a vacuum of $1 \cdot 10^{-4}$ to $3 \cdot 10^{-5}$ mm of mercury column and the presence of a longitudinal focusing magnetic field. As the experiment demonstrated, even with full neutralization of the beam, it is not possible as yet to lower the magnitude of the magnetic field necessary for focusing and reduce the current sagging in the transit tube. This is apparently to be explained by the presence of radial components of the velocities of electrons at the entrance to the transit channel, which is practically always characteristic for the Brillouin systems of focusing, the most prevalent at present.

The application of ion traps is for the time being expedient mainly for preventing destruction of the cathode by positive ions and increasing the service terms of cathodes operating with large current load.

The use of ion traps for improvement of passage of beam current is perspective in the optics of beams close to parallel.

In work [22] a study of the neutralization of the space charge of a cylindrical electron beam with virtual cathode was made in pulse conditinns through the

measurement of the electrical field of the beam's volume charge (the method, described in [12]).

The brief survey given above shows that the elementary theory of electron stream neutralization by ions, — developed at present, does not offer an explanation of all the phenomenon occurring in the zone of ion accumulation and does not permit using its principal deductions for developing electronoptical systems with ion traps. This indicates the necessity of elaborating a strict theory of ion accumulation in the conditions of high vacuum and further experimental investigations in this field.

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Saturation Conditions in Semiconductor Triodes with Large Signals

3

by V.A.Kuz'min

The limits are given of the applicability of the small signal theory for saturation conditions. The work of alloy-type semiconductor triodes in saturation conditions is examined in the case of arbitrary levels of injection. The effect the electron component of the current through the junction has on the resorption time is taken into account. The theoretical deductions are verified experimentally.

Introduction

Interest in the study of saturation, a specific condition in the work of semiconductor triodes that is very frequently met in pulse circuits, has grown in recent years in connection with the wide use of semiconductor triodes in various devices.

The first attempt to offer a theory of saturation conditions was undertaken in work [1], in which by

means of a small-signal equivalent circuit of the triode in the saturation area, formulas were derived for the resorption time of charge carriers in the switching circuit (Fig.1).

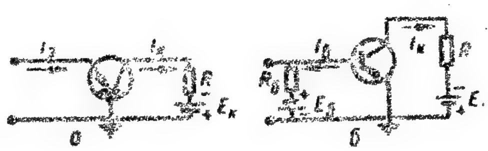

Fig.1. Switching circuit:

a - with general base;
b - with general emitter.

In the works [2,3] the continuity equation was solved for holes in the triode base in the saturation area. Examined herewith in [2] was the case of the effect a square pulse of long duration current has on a switching circuit with a general base and in [3] the more general case of the effect a current pulse of arbitrary duration has on the switching circuit. In both studies the problem was solved within the framework of of the Shokli theory; in them,however, the limits of the applicability of the small signal theory for the saturation area were not examined.

In practical circuits, the saturation conditions are as a rule realized with large signals; therefore, such a theory of saturation conditions represents the

greatest theoretical and practical interest, a theory that might be applied for any levels of injection to a triode with arbitrary base geometry, i.e. in the very general case.

Limits of Applicability of the Small Signal Theory to Saturation Conditions

The small signal theory for amplifying conditions is correct in case the concentration of holes in the base with electron conductance is much less than the concentration of electrons [4]. In a similar way it can be demonstrated that in the saturation area the small signal theory is correct under the same condition -- $p \ll n$, or $p \ll N_d$. The distribution of holes $p(x)$ in the base at the moment of switching t_0 (Fig. 2) with large t_0 was obtained in [2]. With an accuracy to terms of the third order of an infinitesimal

$$p(x) = \frac{W}{2 q D_p S} \left[I_{\delta 1} \left(\frac{2 L_p^2}{W^2} + \frac{x^2}{W^2} \right) + \right.$$
$$\left. + I_{\kappa 1} \left(1 - \frac{2x}{W} \right) \right],$$

in which $I_{\delta 1} = I_{\vartheta 1} - I_{\kappa 1}$ is the base current in saturation conditions; W is the base thickness; S is the area of the junctions of emitter and collector; $L_p = \sqrt{D_p \cdot T_p}$ is the diffusion length of holes in the base.

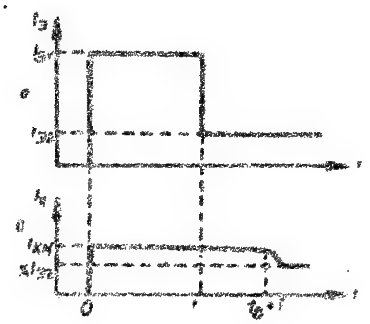

Fig.2. Currents in the switching circuit with general base depending on time: a - input current, b - output current.

Taking into account that $W^2/2L^2\rho = 1 - \beta$ and $\chi = 0$, the concentration of holes in the emitter is equal to

$$p(0) = \frac{W}{2qD_pS}\left[\frac{I_{б1}}{1-\beta} + I_{э1}\right]. \qquad (1)$$

The difference of hole concentration in emitter and collector $\Delta p = p(0) - p(W)$ is found equal to

$$\Delta p = \frac{W}{2qD_pS}\left[\, I_{к1} + I_{кн} \right].$$

Further we will consider that the "degree of saturation" of the triode is sufficiently large, i.e.

$$I_{б1} \gg (1-\beta)\, I_{э1}, \qquad (2)$$

which is usually realized in saturation conditions.

Physically this condition means that the charge

of the holes in the base with saturation exceeds considerably the charge corresponding to the same emitter current in an amplification condition. At the same time it is found that the relationship

$$\frac{\Delta p}{p(0)} = \frac{I_{\text{б}1} + I_{\text{б}2}}{I_{\text{э}}/1 - \beta + I_{\text{б}1}}$$

is substantially less than unity, i.e. the concentrations of holes in the emitter and collector are close in value.

Taking (2) into account, equation (1) is simplified and assumes the form:

$$p(0) = \frac{I_{\text{б}1}}{qD_p \cdot S} \cdot \frac{L_p^2}{W} \qquad (3)$$

We will assume that the condition of the signal's smallness is still fulfilled, if $p/N_d \leqslant 0.1$. According to (3) this corresponds to base currents

$$I_{\text{б}1} \leqslant \frac{W^2}{L_p^2} \cdot 0{,}1 \cdot qD_p S \cdot \frac{Nd}{W} = \frac{W^2}{L_p^2} \cdot I_{\text{э}0} \; ,$$

in which $I_{\text{э}0} = 0.1 q \cdot D_p \cdot S \cdot N_d/W$ is the maximal emitter current in amplifying conditions, corresponding to the small signal. For Russian triodes П1 and П6 $I_{\text{э}0} \approx 0.5$ ma, $I_{\text{б}1} \leqslant 30$ microamperes. We note, however, that the criterion of signal smallness cited above for the current close

to saturation conditions is the logical consequence of the application of the Shokli theory to a one-dimensional model. The quantitative estimates derived will, therefore, be correct only to the extent to which the real triode in saturation conditions is close to the one-dimensional, which is not fulfilled for modern alloy-type triodes.

Saturation Conditions with Arbitrary Levels of Injection

With large levels of injection, electrical field E has an influence on the distribution of holes in the emitter base; calculation of the field is connected with great difficulties, especially in the case of the non-unidimensional triode model. Moreover, appreciable electron currents flow through the junctions. Direct solution of the continuity equation, therefore, is a very complex problem and the examination of the resorption process will be conducted by another method [5].

Let us integrate the continuity equation for holes

$$\frac{\partial p}{\partial t} = -\frac{p - p_n}{\tau_p} - \frac{div\, I_p}{q}$$

in the entire volume of base V and designate

$$q \int_V (p - p_n)\, d\, V = Q\ .$$

in which Q is the full charge of holes in the base, exceeding a balanced charge. Then, instead of the equation in partial derivatives, we obtain an ordinary differential equation of the first order

$$\frac{dQ}{dt} = -\frac{Q}{\tau_p} + I_{\text{эр}} - I_{\text{кр}}\ , \qquad (4)$$

in which I_{er} and I_{cr} are the hole components of the currents of emitter and collector. We note that to derive equation (4) we are not required to consider field E in the base equal to zero, since the divergence of hole current, i.e. a complete differential, enters the continuity equation for holes.

Equation (4) can be used for calculating processes whose constant time exceeds considerably the diffusion time $\tau_D = \frac{W^2}{2D_p}$. Then at each moment of time the distribution of holes in the base can be considered stationary, corresponding to the collector current at that moment of time.

Before turning to calculation of resorption time in the switching circuit (Fig.1), let us examine two subsidiary questions.

(a) Effect of the emitter electron current on the transfer characteristics of a triode connected in a circuit with general emitter.

Let us assume that at the input of a triode operating in amplifying conditions in a circuit with a general emitter, base current pulse $I_{б1}$ is supplied at a certain moment of time. We will examine how the charge Q in the base is changed.

In the amplifying conditions: $I_{er} - I_{cr} =$

$I_б - I_{эn}$ (where $I_{эn}$ is the emitter electron current)
and equation (4) assumes the form:

$$\frac{dQ}{dt} = -\frac{Q}{\tau_p} + I_{б1} - I_{эn}. \qquad (5)$$

According to the known small signal theory formulas correct with sufficiently small base current $I_{б1}$, the electron current I_{en} is connected by linear dependence with the concentration of holes in the base of emitter $p(0)$. On the other hand it can be stated that the complete charge of holes in the base Q is, during the entire transfer process, also proportional to the concentration $p(0)$, inasmuch as the constant time of the transfer process is considerably greater than the time of diffusion of holes through the base τ_D. It can thus be assumed

$$I_{эn} = \frac{Q}{\tau_{эл}}, \qquad (6)$$

in which $1/\tau_{el}$ is the factor of proportionality.

It can be shown that τ_{el} is expressed through the injection factor γ and diffusion time τ_D according to the formula

$$\tau_{эл} = \frac{\gamma \cdot \tau_D}{1 - \gamma}. \qquad (7)$$

Solving equation (5) with consideration of (6), we derive that the charge of the holes in the base

(and, consequently, also the collector current) varies with the constant time $\tau_p^* < \tau_p$, whereupon

$$\frac{1}{\tau_p^*} = \frac{1}{\tau_p} + \frac{1}{\tau_{sx}} . \qquad (8)$$

We note that the value τ_p^* calculated according to formulas (7) and (8) is found to be extremely close to the constant time of the transfer process, calculated from the approximate formula (18) of work [6].

In case the level of injection of holes in the base is not small, then it is, strictly speaking, impossible to consider the electron current proportional to the full charge Q. Measuring the constant time τ_p^* of the transfer characteristics of the triode with large base currents and knowing τ_p, it is possible from the relationships (8) to determine the average τ_{si} for this base current.

(b) <u>the inverted triode operation</u>.

The triode in which collector and emitter change places during operation in amplifying conditions, we will call a triode in inverted connection, or simply inverted triode.

The distribution of holes in the base in saturation conditions and with inverted connection has much in common; for example, in both cases the concentration of holes in the collector is more balanced. Before turning directly to the saturation conditions, it is therefore necessary

briefly to analyze the operation of the inverted triode.

The cross section of an alloy-type triode is shown schematically in Fig.3. The part of the base volume in which the holes are during triode operation in inverted connection, are crosshatched.

Fig.3. Alloy-type semiconductor triode (cross section)

a - collector
b - base
c - emitter

The holes emitted by the central part of the collector having area S_e, land in the emitter, while the holes emitted by the peripheral part of the collector with area $S_c - S_e$ do not land in the emitter and recombine on the surface and in the volume of germanium. Besides, undoubtedly, certain boundary effects occur, which we disregard.

Inside the volume $S_e \cdot W$ the distribution of holes from collector to emitter is linear, but outside this volume the holes are distributed according to the law $p(x,y,z) = \rho_{inv}(W) \cdot f(x,y,z)$, where $\rho_{inv}(W)$ is the concentration of holes in the base at the collector, and $f(x,y,z)$ is the function of distribution depending on many factors, chiefly, on the base geometry and the velocity of surface recom-

bination.

The amplification factor in direct current of the triode in inverted connection is

$$\alpha_{\text{обр}\atop inv} = \frac{qD_p \cdot S_э \cdot p_{\text{обр}}^{inv}(W)/W}{qD_p \cdot S_э \cdot p_{\text{обр}\atop inv}(W)/W + qD_p \cdot (S_к - S_э) \cdot \nabla p_{\text{обр}\atop inv}(W)},$$

a - inverted

in which $\nabla\rho_{inv}(W)$ is the average gradient of holes at the collector outside the $S_e \cdot W$ area.

Hence

$$\nabla p_{\text{обр}\atop inv}(W) = p_{\text{обр}\atop inv}(W)/W \cdot \frac{1 - \alpha_{\text{обр}\,inv}}{\alpha_{\text{обр}\,inv}} \cdot \frac{S_э}{S_к - S_э}.$$

Assuming $\alpha_{\text{обр}\atop inv} \approx 0{,}75 \div 0{,}8, \; \frac{S_э}{S_к - S_э} \approx 0{,}5,$ we derive that the value

$$\nabla p_{\text{обр}\atop inv}(W)/p_{\text{обр}\atop inv}(W) = (0{,}12 \div 0{,}15) \cdot 1/W. \tag{9}$$

The charge of holes in the base with inverted connection is

$$Q = q \cdot p_{\text{обр}\atop inv}(W) S_э W/2 + q p_{\text{обр}\atop inv}(W) \int_{V_1} f(x,y,z)\, dV, \tag{10}$$

where V_1 is the base volume with deduction Se W.

The transfer characteristics of an inverted triode connected in a circuit with general emitter, has the form of exponents, the constant time of which is somewhat reduced with the growth of the base input current. Presented in Table 1 are the constant times of these transfer

characteristics experimentally measured with large base currents.

The duration of the constant time was determined according to calibration marks 1 and 0.1 microseconds of oscillograph IO-4.

Table 1

$I_б$ (ma)	Constant time in microseconds				
	П1Ж №1	П1Ж №2	П1Ж №3	П6Б №41	П6Б №43
5	7.0	6.5	6.5	4.3	4.8
20	7.0	6.0	6.0	4.3	4.2
50	6.0	6.0	6.0	4.0	4.0
100	6.0	5.8	6.0	4.0	4.0
τ_{inv}	7.0	6.5	6.5	4.3	4.8

As is evident from Table 1, with growth of base input current to 100 ma the constant time is reduced not more than 20 % as compared with τ_{inv}, the constant time with small currents.

Assume, for example, it is necessary to find τ_c for the triode П6Б №43 in the case when the base input current is equal to 90 ma. From the table we find the value $\tau_{p\#}$= 4.0 microseconds, corresponding to a base current of 100 ma, which is closest of all to preset value, and the

magnitude τ_{inv} = 4.8 microseconds. By formula (8) we find τ_{el} = 24 microseconds.

Knowing the hole distribution in the base with inverted connection and the electron current connection through the junction with charge Q according to (6),(9) and (10), the time can be calculated of the triode's exit from saturation conditions in the switching circuit taking into account the electron currents through the junction.

Saturation Conditions in the Switching Circuit

Let us assume that at the input of the switching circuit with the general base (Fig.1,a), a pulse of emitter current is served with duration $t_o > 2\tau_p$ and sufficiently large amplitude $I_e > E_c/\alpha R$, so that the triode proved to be in saturation. The condition $t_o > 2\tau_p$ corresponds to the situation that at the moment t_o the hole distribution in the base can be regarded as having been established [3]. At the moment t_o the input current is by a jump changed to the magnitude I_{e1} (Fig.2,a).

The finding of the resorption time T we will conduct with the following assumptions: (1) The life time of holes τ_p in saturation conditions is constantly and at any injection level the same as it is with small signals.

With small signals $\tau_p \cong \tau_{inv}$ [5]. It is consequently assumed that at any injection level $\tau_p = \tau_{inv}$.

(2). In the course of the resorption process, the collector current remains practically constant and equal to $I_{sn} = E_c/R$, which is always realized in the real circuit.

In calculation we use equation (4) for the full charge of holes in the base. In connection with the fact that in saturation conditions the concentration of holes is more balanced both in the emitter and in the collector, the electron current flows not only through the emitter but also through the collector. Taking into account the direction of the hole and electron currents (Fig.4)* (*the electron current of the collector in saturation conditions flows from the collector to the base — technical direction —, since the electrons flow from the base to the collector), equation (4) assumes the form:

$$\frac{dQ}{dt} = -\frac{Q}{\tau_p} + i_б - i_{кр} - i_{эn} - i_{кn} .$$

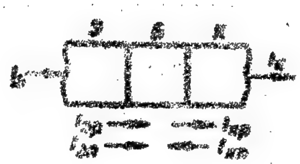

Fig.4. Direction of currents in semiconductor triode in saturation conditions.

As was demonstrated above, the concentration of

holes in the base at emitter and collector, $\rho(0)$ and $\rho(W)$, are close in magnitude. It can, therefore, be assumed

$$I_{\text{н}I} = \frac{S_c}{S_e} I_{\text{н}N} \,. \qquad (11)$$

The charge of holes in saturation conditions is connected with the concentration at the collector $\rho(W)$ by the dependence:

$$Q = q\rho(W) \cdot S_e W + q\rho(W) \cdot \int_{V_1} f(x,y,z)\, dV \,.$$

In fact the distribution of holes inside the $S_e \cdot W$ volume can be considered uniform, $\rho(0) \approx \rho(W)$, and outside the S_e (W) area the holes are distributed according to the same law (16) as in the inverted connection as well (we disregard the boundary effect at the emitter). Therefore with one and the same charge Q during triode operation in saturation conditions and in the inverted connection

$$\frac{p(W)}{p_{\text{обр}}(W)} = \frac{S_c\, W/2 + \int_{V_1} f(x,y,z)\, dV}{S_e \cdot W + \int_{V_1} f(x,y,z)\, dV} \,. \qquad (12)$$

Since the space occupied by holes outside the $S_e \cdot W$ area is undoubtedly larger than $(S_c - S_e) \cdot W_1$ (Fig.3) and the volume recombination in the length W_1 can be disregarded (the gradient of holes inside the ring $(S_c - S_e)\, W_1$ is not changed), then

$$\int_{V_1} f(x,y,z)\,dV > (S_k - S_э)\int_0^{W_1}\left[1 - \frac{\nabla \rho_{обр}^{inv}(W)}{\rho_{обр}(W)}\cdot x\right]dx = (S_k - S_э)\times$$

$$\times W_1\left[1 - \frac{\nabla \rho_{обр}(W)\cdot W_1}{\rho_{обр}(W)\cdot 2}\right].$$

Taking into account that for alloy-type triodes П1 and П6

$$S_k - S_э \approx 2S_э,\ W_1 \approx 2W,\ \frac{\nabla \rho_{обр}^{inv}(W)}{\rho_{обр}(W)} \leqslant 0{,}15\cdot 1/W$$

instead of (12), we derive $\frac{\rho(W)}{\rho_{обр}(W)} > 0{,}9.$ Thus, $0{,}9 < \frac{\rho(W)}{\rho_{обр}(W)} < 1.$ i.e. with one and the same charge Q the concentrations $\rho(W)$ and $\rho_{inv}(W)$ are close in magnitude and consequently, in both cases the collector electron currents are identical. Therefore

$$I_{кэ} = \frac{Q}{\tau_{э.л}}. \qquad (13)$$

With large injections, instead of τ_{el} in formula (13), should be substituted $\tilde{\tau}_{el}$ determined by means of Table 1 and correlations (8).

Finally the equation for the full charge taking (11) and (13) into account, assumes the form:

$$\frac{dQ}{dt} = -\frac{Q}{\tau_1} + I_э - I_{кэ}. \qquad (14)$$

in which

$$\frac{1}{\tau_1} = \frac{1}{\tau_p} + \frac{1 + S_s/S_k}{\tau_{sd}}. \qquad (15)$$

The calculation of the resorption time is divided into two stages:

Determination of the charge of holes in the base at the moment of switching.

Inasmuch as it is assumed that $t_0 > 2\tau_p$, then according to [3], the distribution of holes in the base at moment t_0 can be considered steady. The charge Q is determined from equation (14), whereupon $I^e = I_{e1}$, and $\frac{dQ}{dt} = 0$

$$Q_0 = \tau_1 (I_{э1} - I_{к н}).$$

Calculation of resorption time T

After switching with $t > t_0\ I_э = I_{э2} \frac{dQ}{dt} \neq 0.$ With $t = t_0,\ Q = Q_0.$ The number of holes in the base at the moment of exit from saturation can be determined by the expression:

$$Q(t_0 + T) = \frac{I_{кн}(1-\beta)}{\beta}\tau_p. \qquad (16)$$

In reality, the number of holes in the base with $t = t_0 +$ T must correspond to the stationary distribution in amplifying conditions with collector current $I_{кн}$, since the concentration necessary for balancing (i.e. the

diffusion time τ_D) is usually much less than the resorption time.

We note that consideration of electrical field E and the real geometry of the base must introduce a correction in expression (16). But the charge remaining in the base to the moment of the triode's exit from saturation is small in comparison to the full charge during saturation, and the correction can apparently be considered insignificant.

Solution of equation (14) for the resorption stage has the form:

$$Q(t) = (I_{\text{э}1} - I_{\text{э}2})\,\tau_1\, e^{-(t-t_0)/\tau_1} + (I_{\text{э}2} - I_{\text{кн}})\cdot\tau_1.$$

According to (16)

$$(I_{\text{э}1} - I_{\text{э}2})\cdot\tau_1\cdot e^{-T/\tau_1} + (I_{\text{э}2} - I_{\text{кн}})\cdot\tau_1 = \frac{I_{\text{кн}}(1-\beta)}{\beta}\,\tau_\sigma.$$

Hence

$$T = \tau_1 \ln \frac{I_{\text{э}1} - I_{\text{э}2}}{I_{\text{кн}} + \frac{I_{\text{кн}}(1-\beta)}{\beta}\cdot\frac{\tau_\sigma}{\tau_1} - I_{\text{э}2}}.$$

The magnitude $\frac{I_{\text{кн}}(1-\beta)}{\beta}\cdot\frac{\tau_\sigma}{\tau_1}$ enters the formula under the logarithm sign and has a weak effect on the value of the resorption time. It is, therefore, not expedient to simplify, having assumed $\tau_\rho = \tau_1$ and $\beta = \alpha$. Then

$$T = \tau_1 \ln \frac{I_{\text{э}1} - I_{\text{э}2}}{I_{\text{кн}}/\alpha - I_{\text{э}2}}. \qquad (17)$$

Similarly for circuit with general emitter (Fig.1,b)

$$T = \tau_1 \ln \frac{I_{b1} - I_{b2}}{I_{kn}/b - I_{b2}}, \qquad (18)$$

where b is the amplification factor of current in the circuit with general emitter.

The expressions (17) and (18) differ from the corresponding formulas, derived in the works [2,3] by the coefficient before the logarithm, which reflects the dependence of resorption time on the electron currents through the junction. As should also be expected, consideration of electrical field E did not cause a change of the formula for resorption time.

Experiment

The main purpose of the experiment was to verify the assumption of the permanence of the life time of holes in saturation conditions τ_p with large signals.

Presented in Fig.5 are the results of measurements for one of the П14 triodes in the switching circuit with general base. The moment of resorption termination is determined just as in work [2], i.e. at the point of greatest steepness of trailing edge. The magnitude T_1 was determined by means of formula (17). With use of the data in Table 1, the value τ_{e1} was found from (8). The ratio of areas S_e/S_c is equal to the ratio of the static

junction capacitances C_e/C_c measured with one and the same negative bias on the junction. Then, τ_p was determined according to (15).

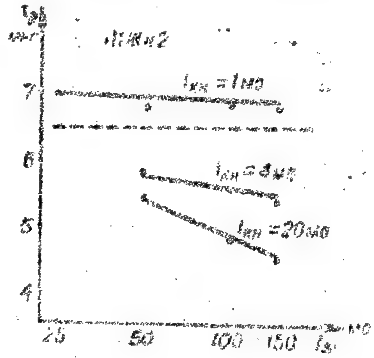

Fig.5. Life time of holes in saturation conditions with high level of injection $I_{e2} = 0$; $\alpha = 0.97$; $S_e/S_c = 0.35$.

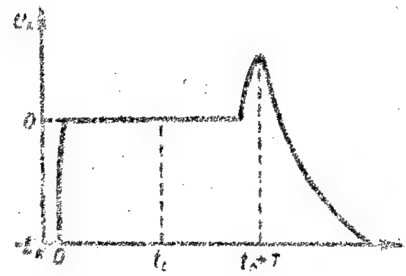

Fig. 6. Shape of voltage at collector in the circuit of Figure 1,b. for the case $|I_{б_2}| > I_{кн}$.

With large collector currents τ_p is close to τ_{inv} (dotted line in Fig.5); with increase of emitter current I_{e1} at constant collector current I_{cn} (i.e. with growth of injection level) τ_p is changed very little. The assumption of the independence of the life time of holes from the level of injection is thus found correct by experiment.

The τ_p measured at large collector currents in saturation conditions is found to be less than τ_{inv} (Fig.5). This question stands in need of further investigation. Measurements in the circuit with the general emitter yield concurrence of experimental data with theory that is approximately the same as in the circuit

with the general base; however, if $|I_{б2}| > 2I_{cn}$ the form of voltage on the collector is changed; a transient overshoot (Fig.6) rises at the end of the resorption stage in the collector. The voltage splash is the more noticeable, the better the inequation $|I_{б2}| > 2I_{cn}$ is fulfilled.

The explanation of this phenomenon is as follows. In case $|I_{б2}| > 2I_{cn}$, emitter current I_{e2} is negative and surpasses in modulus the collector current I_{cn}. During the process of resorptinn, the holes depart from the base both through the collector and through the emitter; however, inasmuch as $|I_{e2}| > I_{cn}$, the emitter is closed faster than the collector and the base potential relative to the emitter is raised. The collector potential remains some time close to the base potential (inasmuch as the concentration of holes in the base at the collector is still more balanced) with the result that on the collector as well as on the base, the voltage relative to the emitter begins to rise. As soon as the collector is closed, its potential begins to drop.

In the presence of the U_c voltage splash the resorption time should be measured from $t=t_0$ to the peak of the transient overshoot.

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Glossary of Russian letters in formulas:

Э - emitter
К - collector
КН - constant collector current
ЭЛ - electron

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Differentiating and Integrating Devices with Positive Feedback

4

by A.I.Petrenko

Differentiating and integrating devices that use positive feedback are generalized; a general method is proposed for their analysis and calculation in the example of a concrete circuit.

The possibility is shown of eliminating the influence that the end value of the internal resistance of the input signal's source has on the accuracy of performing a mathematical action.

Differentiating and integrating elements made in the form of combinations of passive RC-circuit and electronic amplifier, enveloped by deep negative feedback (Fig.1), are being widely used in the electronic units of computing and simulating systems [1,2,3,4].

The structural error of such elements (with amplification factor of the amplifier equal to K) is known to be approximately K times less than the structural error

of the ordinary passive RC circuit. Under structural error is usually implied the error caused by the circumstance that in reality as well as in the case of differentiation and integration, the current through capacitance C depends not on the input signal U_1 but on the difference of voltages $U_1 - U_2$, where U_2 is the output voltage, equal, in case of differentiation, to the voltage drop at resistance R, in case of integration, to the voltage at the plates of integrating capacitor C.

Under the condition of grid current absence in the first amplifier cascade for the device diagrammed in Fig.1, the following correlations are respectively correct [5]:

$$\left.\begin{aligned} U_2(p) &= -\frac{K}{K+1} RCp\, U_1(p) - RC\frac{1}{K+1} p\, U_2(p) \\ U_2(p) &= -\frac{K}{K+1}\cdot\frac{1}{RC}\,\frac{U_1(p)}{p} - \frac{1}{RC(K+1)}\cdot\frac{U_2(p)}{p} \end{aligned}\right\} \qquad (1)$$

in which $U_2(p)$ and $U_1(p)$ are operational representations of output and input voltages U_2 and U_1.

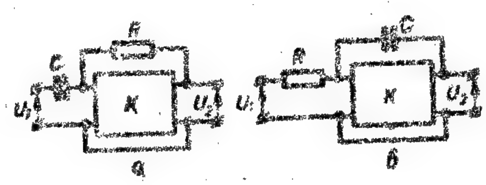

Fig.1. Basic circuit diagram of connection of a passive RC circuit and an electronic amplifier:
a - electronic differentiator
b - electronic integrator

In this way, the greater the amplification factor K, the more accurately is the operation of differentiation or integration performed. The increase of K, however, requires the construction of complex multicascade circuits of direct current amplifiers with a large amplification factor in voltage, circuits having high stability. Representing the electronic amplifier in the form of a triple pole system, Fig. 1 can be pictured in the form of Fig. 2, where K' is the equivalent amplifier. Its input connectors are terminals 1 - 3, output 2 - 3, but not 3 - 2, as in amplifier K (Fig. 1).

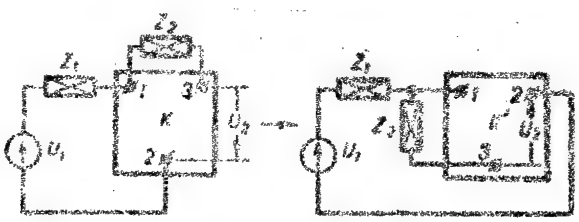

Fig. 2. Changing over from amplifier K, bringing about negative feedback, to amplifier K' bringing about positive feedback.

Considering the phase turn of amplifier K, it can be stated that the voltage at the input and output of amplifier K' will be in phase. Amplifier K', therefore, brings about positive feedback in the input circuit, and the voltage on its output terminals 2 - 3 is formed with the input voltage U_1 subject to differentiation or

integration.

Equations (1) which describe the work of the functional device as a whole, are transformed for the Fig.2 circuits as follows:

$$\left.\begin{aligned} U_2(p) &= K' RCp\, U_1(p) + (1-K')\, RCp\, U_2(p) \\ U_2(p) &= K' \frac{1}{RC}\cdot\frac{U_1(p)}{p} + \left(1-K'\right)\frac{1}{RC}\cdot\frac{U_2(p)}{p} \end{aligned}\right\}, \qquad (1a)$$

where $K' = K/K + 1$.

As is evident from the expression (1a), the structural error of the device will be absent when $K' = 1$, which corresponds to $K = \infty$.

In this way, the accurate (without structural errors) operation of differentiation or integration can be performed also with the use of an amplifier having an amplification factor equal to unity, but realizing positive feedback in the input circuit, instead of an amplifier tending toward infinity. From the physical viewpoint, the processes taking place in the Fig.2 circuit are explained as follows: the output voltage U_2 of amplifier K', being formed with input voltage U_1, compensates in the input circuit the voltage drop at resistance R in case of differentiation or the voltage on capacitor C in case of integration; since with $K' = 1$ or minus C in the input circuit, the voltages on amplifier terminals 1 - 3 and 2 - 3 have identical phase and amplitude.

The possibility of using for compensation amplifiers with amplification factor close to unity makes expedient the use of a cathode follower [6].

In Fig.3 is shown in principle the circuit of such a device, operating as differentiator or integrator depending on the concrete sense of impedances $Z_1(p)$ and $Z_2(p)$.

The output voltages taken from element Z_2 for the integrator and differentiator, developed in cathode followers, are respectively equal to:

$$\left.\begin{aligned} U_2(p)_{\substack{\text{инт}\\ \text{int}}} &= \frac{1}{RC\left(1+K\frac{R_i}{\mu R}\right)}\cdot\frac{U_1(p)}{p}-\frac{1-K}{RC\left(1+K\frac{R_i}{\mu R}\right)}\cdot\frac{U_2(p)}{p} \\ U_2(p)_{\substack{\text{диф}\\ \text{dif}}} &= RC\cdot p\,U_1(p)-RC\left(1-K+K\frac{R_i}{\mu R}\right)p\,U_2(p) \end{aligned}\right\}\cdot (2)$$

a- int egration
b -differentiation

in which $K=\frac{\mu R_k}{R_i+(1+\mu)R_k}$ is the cathode follower's transmission factor.

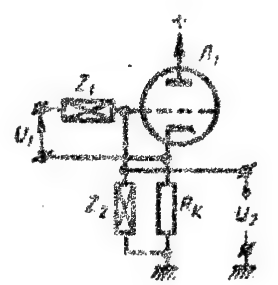

Fig.3. Circuit of a differentiating and integrating device in a cathode follower.

As follows from expressions (2), the device of Fig.3 has the better operational characteristic, the closer the cathode follower's amplification factor K is to unity, the less R_i/R and the more μ are.

Thus, the use of one tube does not make it possible to perform an accurate mathematical operation and the presence of at least two tubes is essential; at the same time feedback of the required polarity can be realized by the following possible methods:(a) from anode $Л_2$ to grid $Л_1$; (b) between cathodes $Л_2$ and $Л_1$; (c) from cathode $Л_2$ to anode $Л_1$. It is interesting to note that all these variants, isolated one from another, without distinguishing the general principle of their operation, were used by various authors in separate circuit developments of active differentiators and integrators.

So, the first type of possible positive feedback was applied by H.Wittke [7,8] when constructing the differentiator and integrator having in principle the circuit shown in Fig.4.

The second type of positive feedback in a two-cascade circuit was used by Tolles and Semitt [9] when creating the differentiator shown in Fig.5.

And finally, the feedback from cathode $Л_2$ to anode $Л_1$ was applied in the integrator circuit described by

Williams (Fig.6) [10].

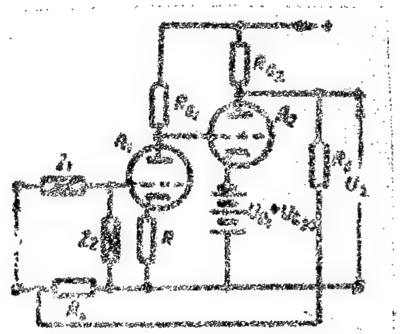

Fig.4. Circuit of operational device proposed by H. Wittke

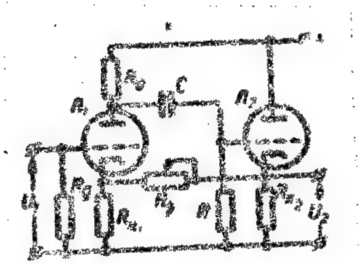

Fig.5. Circuit of Tolles and Semitt differentiator with positive cathode feedback

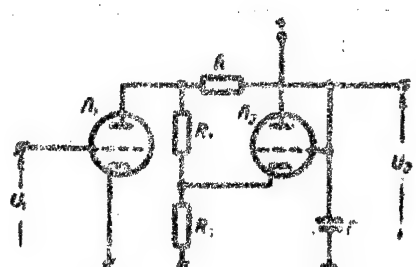

Fig.6. Skeletal circuit of Williams integrator

For substantiation of the general method of analysis and calculation of these circuits, we find the value of the positive feedback transmission factor β, essential

for performance of accurate operational action, depending on the amplification factor of the whole amplifier without feedback K_y and elements of the circuit on the basis of the general case (Fig.7).

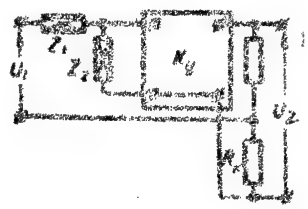

Fig.7. General case of operational circuit with positive feedback.

According to the theory of amplifiers with feedback, the amplification factor of the entire device is equal to

$$K_{oc}(p) = \frac{U_2(p)}{U_1(p)} = \frac{\frac{Z_2(p)}{Z_1(p)+Z_2(p)+R_x} \cdot K_y}{1 - K_y\beta \frac{Z_2(p)}{Z_1(p)+Z_2(p)+R_x}} . \qquad (3)$$

For realization of an operational action circuit, it is essential that $K_{oc}(p)$ be determined by the quotient of two impedances $Z_2(p)$ and $Z_1(p)$ which is possible with

$$K_y \cdot \beta = 1, \qquad (4)$$

at the same time expression (3) is simplified to

$$K_{oc}(p) = K_y \frac{Z_2(p)}{Z_1(p)+R_x} . \qquad (5)$$

It is not hard to see that in the case $Z_2 = \frac{1}{pC}$ and $Z_1 = R$, the condition (4) is the condition of accurate integration, whereupon the constant time of integration τ_0 is determined with consideration of R_g, i.e.

$$K_{oc}(p) = K_y \cdot \frac{1}{p\tau_0}, \tag{5a}$$

where

$$\tau_0 = C(R + R_g).$$

For differentiation $\left(Z_1 = \frac{1}{pC},\ Z_2 = R\right)$ the condition of accurate mathematical operation is somewhat different from expression (4) and assumes the form

$$K_y \beta \frac{Z_2}{Z_2 + R_g} = K_y \cdot \beta \cdot \frac{R}{R + R_g} = 1. \tag{6}$$

In this case

$$K_{oc}(p) = K_y \cdot \frac{Z_2(p)}{Z_1(p)} = K_y p \tau, \tag{7}$$

where

$$\tau = RC.$$

Formulas (5) and (7) simultaneously determine also the stability of these functional devices, showing that notwithstanding in essence the critical value of the positive feedback (4), the entire device as a whole behaves quite stable in a broad frequency range [7,11].

We indicate still another advantage of operational circuits with positive coupling, and namely: the possibility of compensation of structural error determined by

the terminal value of the internal resistance R_0 of the signal source, which in the case of using negative operational coupling does not depend at all on the amplification factor of the amplifier used.

With terminal value R_0 in case of integration additional error does not arise, as the connection of Ro in the composition of series resistance R is possible. In this case the condition (4) is preserved, and the expression (5a) is set forth in the form:

$$K_{oc}(p) = \frac{1}{pC(R + R_{\kappa} + R_{0})}. \qquad (5b)$$

But in the case of differentiation, on the contrary, to preserve the form of expressimn (7), it is necessary to modify the condition of accurate mathematical operation as follows:

$$K_{y}\beta\frac{R}{R + R_{\kappa} + R_{0}} = 1. \qquad (6a)$$

Consequently, in the latter case, the cascade with cathode load for feeding the signal at the input circuit can be excluded.

On the basis of the foregoing, the following procedure of analysis and calculation of operational circuits with positive coupling can be recommended:

(a) the amplification factor of the amplifier

used is determined without taking feedback into account;

(b) the transmission factor β of the positive feedback is determined;

(c) correlations for selection of feedback elements are found by means of expressions (4) or (6).

Using this method, all the calculated correlations are readily derived for circuits of Figs. 4,5,6, cited in the original works.

As an example we examine the application of the proposed method to analysis of the differentiator, shown in Fig.8.

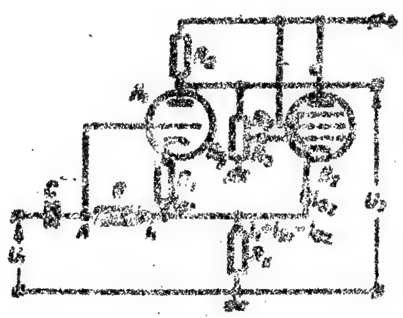

Fig.8. Circuit of an active differentiator with positive feedback through general cathode resistance.

In this circuit, the compensation of voltage that bears the error, occurs in the input circuit, in which enter the elements C,R and the general cathode resistance R_c.

As is evident from the circuit, the voltage separa-

ting out in R, is amplified by tube Л_1 and simultaneously changes the phase on its anode.

The second cascade in Л_2 operates in the cathode follower conditions, the current of this tube, controlled by means of R_β, separates out in resistance R_c the voltage in antiphase with the input, i.e. voltage U^R.

For simplification of deductions assuming $R_a \ll R_\beta$ and $R_c \ll R$, which is correct for the majority of practical cases, we find for our circuit

$$K_1 = \frac{\mu_1 R_a}{R_a + R_x + R_{i1} + (1 + \mu_1) R_1}$$

and $\beta = \beta_+ - \beta_- = m K_2 - \dfrac{R_x}{R_a}$,

in which $K_2 = \dfrac{\mu_2 R_k}{R_{i2} + (1 + \mu_2) R_k}$ is the cascade transmissiun factor in Л_2; $m = \dfrac{R_2}{R_2 + R_3}$ is the transmission factor of potentiometer R_β.

According to (6)

$$K_1 \left(m K_2 - \frac{R_x}{R_a} \right) = 1.$$

From which

$$m = \frac{\dfrac{1}{K_1} + \dfrac{R_x}{R_a}}{K_2} \qquad (8)$$

But this expression can be derived by examining the processes that take place in the input circuit, i.e. with the assumptions made, determining the condition of equality $U_R = U_c\ (i_1 + i_{a1} - i_{a2})$ through the current

present in the circuit.

Expression (8) is approximate but the accurate setting of potentiometer R_3 is done in tuning the circuit when, with a given input signal, the absence of a variable voltage between points A and the ground is achieved, since in the case of full compensation the dynamic resistance between them is equal to zero.

In this way, operational circuits with positive feedback make it possible in principle without any kind of technical difficulties, to perform the required mathematical operation with ideal accuracy.

Reports on the errors of certain of these circuits have already been made [7,9,11] and the findings (while additional careful research in the whole question of errors is still required) allow us to hope that, especially in the design of small models, in which simplicity and compactness play an important role, the compensation device with positive feedback will be able to compete successfully with the devices now widely used, that are designed according to circuit diagram Fig. 1.

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Calculation of Ribbed Structure Helical Type Moderating Systems

5

by V.A.Slyusarskiy

The propagation is analysed of an axially-symmetrical wave in a spiral placed in an artificially anisotropic dielectric and in an irised waveguide with conducting diaphragms.

Moderating systems in which the reduction of the wave phase velocity is achieved on account of several elements, find use in many fields of engineering. To such systems belong the spiral in a dielectric [1 - 3], the spiral in an irised waveguide [4,5], the coaxial waveguide with ribs on the external and internal conductors [6] and others. Of no less interest, however, are moderating systems that consist of a spiral placed in a waveguide partially filled with anisotropic dielectric. As is known the anisotropic medium filling the waveguide can be created artificially. Such a medium is, for example, plasma. In addition, such a medium can be made in the form of discs of a uniform isotropic dielectric arranged period-

-cally in the waveguide. The analysis of such a device is given in work [7]. Employing the methods proposed in this work, let us examine the spiral found in the waveguide with diaphragms (Fig.1) and determine the system properties for the case of dielectric conducting diaphragms.

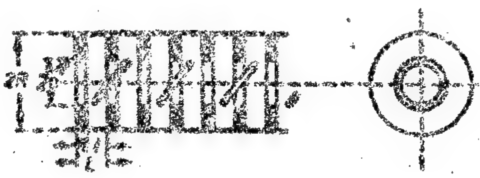

Fig.1.

Let us assume that the material of the diaphragm has dielectrical penetrance ε and magnetic penetrance μ. Assuming the system conductors ideal, substituting the spiral by a cylinder with helical conductance and taking into account only the axially-symmetrical waves, we can write the expressions for the fields. The fields inside the spiral $(0 \leqslant r \leqslant a)$:

$$\left.\begin{aligned} E_{z1} &= E_0 I_0(\gamma_1 r) & H_{z1}\ B_1 I_0(\gamma_1 r) \\ E_{r1} &= jE_0 \frac{\beta}{\gamma_1} I_1(\gamma_1 r) & H_{r1} = jB_1 \frac{\beta}{\gamma_1} I_1(\gamma_1 r) \\ H_{\varphi 1} &= jE_0 \frac{\beta_0}{\gamma_1} I_1(\gamma_1 r) & E_{\varphi 1} = -jB_1 \frac{\beta_0}{\gamma_1} I_1(\gamma_1) \end{aligned}\right\}. \qquad (1)$$

In accordance with [7], we determine the fields in the zone of diaphragms $(a \leqslant r \leqslant R)$ as follows:

$$
\left.\begin{aligned}
E_{z2} &= A_2\,[J_0(\gamma_2 r)\,N_0(\gamma_2 R) - J_0(\gamma_2 R)\,N_0(\gamma_2 r)]\,\frac{Z(z)}{\varepsilon(z)}\\
E_{r2} &= -\frac{1}{\gamma_2}\,A_2\,[J_1(\gamma_2 r)\,N_0(\gamma_2 R) - J_0(\gamma_2 R)\,N_1(\gamma_2 r)]\,\frac{1}{\varepsilon(z)}\,\frac{dZ(z)}{dz}\\
H_{\varphi 2} &= j\,\frac{\beta_0}{\gamma_2}\,A_2\,[J_1(\gamma_2 r)\,N_0(\gamma_2 R) - J_0(\gamma_2 R)\,N_1(\gamma_2 r)]\,Z(z)\\
H_{z2} &= B_2\,[J_0(\gamma_2 r)\,N_1(\gamma_2 R) - J_1(\gamma_2 R)\,N_0(\gamma_2 r)]\,\frac{Z^*(z)}{\mu(z)}\\
H_{r2} &= \frac{1}{\gamma_2}\,B_2\,[J_1(\gamma_2 r)\,N_1(\gamma_2 R) - J_1(\gamma_2 R)\,N_1(\gamma_2 r)]\,\frac{1}{\mu(z)}\,\frac{dZ^*(z)}{dz}\\
E_{\varphi 2} &= -j\,\frac{\beta_0}{\gamma_2}\,B_2\,[J_1(\gamma_2 r)\,N_1(\gamma_2 R) - J_1(\gamma_2 R)\,N_1(\gamma_2 r)]\,Z^*(z)
\end{aligned}\right\} \quad (2)
$$

In correlations (1) and (2) $\beta_0 = \omega/c$; $\beta = \omega/v$; $\gamma^2{}_1 = \beta^2 - \beta_0^2$.

The functions $Z(z)$ and $Z^*(z)$ are preset by the equations:

$$
\frac{d^2 Z(z)}{dz^2} + p^2(z)\,Z(z) = 0; \qquad \frac{d^2 Z^*(z)}{dz^2} + p^{*2}(z)\,Z^*(z) = 0, \quad (3)
$$

where $p_1{}^2 = \beta^2{}_0 - \gamma^2{}_2$; $p^{*2}_1 = \beta^2{}_0 - \gamma^2{}_3$ — in the slits $(0 \leqslant z \leqslant l)$ and $p^2{}_2 = \varepsilon\mu\,\beta^2{}_0 - \gamma^2{}_2$; $p_2{}^{*2} = \varepsilon\mu\,\beta^2{}_0 - \gamma^2{}_3$ — in the diaphragms $(l \leqslant z \leqslant l+q)$.

The solution of equations (3) can be written as

$$
Z(z) = v_1(z) - \frac{v_1(L) - \rho_1}{v_2(L)}\,v_2(z); \quad Z^*(z) = v_1{}^* z - \frac{v_1{}^*(L) - \rho_1{}^*}{v_2{}^*(L)}\,v_2{}^*(z).
$$

in which

$$
\left.\begin{aligned}
v_1 &= \cos p_1 z\\
v_2 &= \frac{1}{p_1}\sin p_1 z
\end{aligned}\right\}\; 0 \leqslant z \leqslant l;
$$

$$
\left.\begin{aligned}
v_1 &= \cos p_1 l \cos p_2 (z-l) - \frac{p_1 \varepsilon}{p_2}\sin p_1 l \sin p_2 (z-l)\\
v_2 &= \frac{1}{p_1}\sin p_1 l \cos p_2 (z-l) - \frac{\varepsilon}{p_2}\cos p_1 l \sin p_2 (z-l)
\end{aligned}\right\}\; l \leqslant z \leqslant l+q;
$$

$$\left.\begin{aligned} v_1^* &= \cos p_1^* z \\ v_2^* &= \frac{1}{p_1^*}\sin p_1^* z \end{aligned}\right\} 0 \leqslant z \leqslant l$$

$$\left.\begin{aligned} v_1^* &= \cos p_1^* l \cos p_2^* (z-l) - \frac{p_1^* \mu}{p_2^*} \sin p_1^* l \sin p_2^* (z-l) \\ v_2^* &= \frac{1}{p_1^*}\sin p_1^* l \cos p_2^* (z-l) - \frac{\mu}{p_2^*}\cos p_1^* l \sin p_2^* (z-l) \end{aligned}\right| l \leqslant z \leqslant l+q.$$

The functions ρ and ρ^* can be found by way of utilizing the periodic properties of solutions $Z(z)$ and $Z^*(z)$.

$$Z_1(z+L) = \rho_1 Z_1(z); \qquad Z_2(z+L) = \rho_2 Z_2(z);$$
$$Z_1^*(z+L) = \rho_1^* Z_1^*(z); \qquad Z_2^*(z+L) = \rho_2^* Z_2^*(z).$$

Thus

$$\rho_1 = e^{-j\psi}; \quad \rho_2 = e^{j\psi}; \quad \rho_1^* = e^{-j\psi^*}; \quad \rho_2^* = e^{j\psi^*}.$$

The values ρ_1 and ρ_1^* correspond to direct waves, ρ_2 and ρ_2^* to revertive waves. The phase angles ψ and ψ^* (the change of wave phases within the limits of period L) are determined by the expressions:

$$\left.\begin{aligned} \cos\psi &= \cos p_1 l \cos p_2 q - \frac{p_1^2 \varepsilon^2 + p_2^2}{2 p_1 p_2 \varepsilon} \sin p_1 l \sin p_2 q \\ \cos\psi^* &= \cos p_1^* l \cos p_2^* q - \frac{p_1^{*2} \mu^2 + p_2^{*2}}{2 p_1^* p_2^* \mu} \sin p_1^* l \sin p_2^* q \end{aligned}\right| \quad (4)$$

With $r=a$ using the boundary conditions in the helically conducting cylinder:

$$E_{z1} = E_{z2}; \qquad E_{z1}\sin\Theta + E_{\varphi 1}\cos\Theta = 0;$$
$$E_{\varphi 1} = E_{\varphi 2}; \qquad H_{\varphi 1}\cos\Theta + H_{z1}\sin\Theta = H_{\varphi 2}\cos\Theta + H_{z2}\sin\Theta,$$

averaged beforehand according to period L, we derive the dispersion correlation for the spiral in the waveguide with diaphragms of magnetodielectric:

$$\left(\frac{\gamma_1}{\beta_0}\operatorname{tg}\Theta\right)^2=\frac{\gamma_1\Delta_2 I_1(\gamma_1 a)\,Z^*\,[\gamma_2\Delta_3 I_1(\gamma_1 a)\,Z_\varepsilon-\gamma_1\Delta_4 I_0(\gamma_1 a)\,Z]}{\gamma_2\Delta_1 I_0(\gamma_1 a)\,Z_\varepsilon\,[\gamma_1\Delta_2 I_0(\gamma_1 a)\,Z^*-\gamma_2\Delta_3 I_1(\gamma_1 a)\,Z^*_\mu]}, \quad (5)$$

in which

$$\Delta_1=J_0(\gamma_2 a)N_1(\gamma_2 R)-J_1(\gamma_2 R)N_0(\gamma_2 a);\quad Z=\int_0^L Z(z)\,dz;$$

$$\Delta_2=J_1(\gamma_2 a)N_1(\gamma_2 R)-J_1(\gamma_2 R)N_1(\gamma_2 a);\quad Z_\varepsilon=\int_0^l Z(z)\,dz+\frac{1}{\varepsilon}\int_l^{l+q} Z(z)\,dz;$$

$$\Delta_3=J_1(\gamma_2 a)N_0(\gamma_2 R)-J_0(\gamma_2 R)N_1(\gamma_2 a);\quad Z^*=\int_0^L Z^*(z)\,dz;$$

$$\Delta_4=J_0(\gamma_2 a)N_0(\gamma_2 R)-J_0(\gamma_2 R)N_0(\gamma_2 a);\quad Z^*_\mu=\int_0^l Z^*(z)\,dz+\frac{1}{\mu}\int_l^{l+q} Z(z)\,dz.$$

Let us examine the system pictured in Fig.1, under the condition that $\rho_1 l \ll 1$, $\rho_2 q \ll 1$, $\rho_1^* l \ll 1$, $\rho_2^* q \ll 1$. If these inequations are fulfilled, then expressions (4) afford the possibility of representing the zone in which the diaphragms ($a \leqslant r \leqslant R$) are, as being filled with a continuous anisotropic magnetodielectric. The components of its dielectrical and magnetic penetrances are coupled with the geometric dimensions as follows:

$$\left.\begin{aligned}\varepsilon_z&=\frac{(l+q)\varepsilon}{l\varepsilon+q} & \varepsilon_r&=\frac{l+q\varepsilon}{l+q} & \mu_\varphi&=\frac{l+q\mu}{l+q}\\ \mu_z&=\frac{(l+q)\mu}{l\mu+q} & \mu_r&=\frac{l+q\mu}{l+q} & \varepsilon_\varphi&=\frac{l+q\varepsilon}{l+q}\end{aligned}\right\}. \quad (6)$$

The radial propagation constants γ_2 and γ_3 are now determined in the form of correlations:

$$\gamma_2^2 = \varepsilon_r \mu_\varphi \beta_0^2 - \frac{\varepsilon_z}{\varepsilon_r}\beta^2 ; \qquad \gamma_3^2 = \mu_r \varepsilon_\varphi \beta_0^2 - \frac{\mu_z}{\mu_r}\beta^2 .$$

In case of continuous anisotropic magnetodielectric, the dispersion dependence (5) changes to the following:

$$\left(\frac{\gamma_1}{\beta_0}\,\mathrm{tg}\,\theta\right)^2 = \frac{\gamma_1\varepsilon_2 I_1(\gamma_1 a)[\gamma_2\Delta_2 I_1(\gamma_1 a) - \gamma_1\varepsilon_2\Delta_3 I_1'(\gamma_1 a)]\mu_2}{\gamma_2\Delta_1 I_1'(\gamma_1 a)[\gamma_1\Delta_4\varepsilon_2 I_1'(\gamma_1 a) - \gamma_2\Delta_2 I_1(\gamma_1 a)]} . \qquad (7)$$

Analysis of equation (7) shows that in case of large arguments of Bessel functions and $R \to \infty$, the phase velocity in such a moderating system can be found from the expression

$$\left(\frac{c}{v}\,\mathrm{tg}\,\theta\right)^2 = \frac{1+\sqrt{\varepsilon_z\varepsilon_r}}{1+\sqrt{\mu_z\mu_r}}\sqrt{\mu_z\mu_r} . \qquad (8)$$

It must be observed that the assumption $R \to \infty$ does not disturb the community of considerations, since with high frequencies the electromagnetic field is concentrated close to the spiral. From the formula (8) it follows that in the system being explored retardation depends on the spiral parameters as well as on the properties of the anisotropic magnetodielectric. Comparing (8) with the corresponding results of work [2] (The latter can be derived from (8) in case $\mu_z = \mu_r = 1$; $\varepsilon_z = \varepsilon_r$), it can be concluded that with large retardations (c/v), the wave phase

velocity is varied proportionally to $(\varepsilon_2\varepsilon_r)^{-\frac{1}{4}}$ in the anisotropic case, whereas in the isotropic case it is proportional to $\varepsilon^{-\frac{1}{2}}$. At high frequencies, consequently, retardation in the system being explored can reach greater values than the value of retardation in a spiral surrounded by an isotropic dielectric.

In the case of small arguments of Bessel functions we derive another expression for determination of the phase velocity:

$$\left(\frac{c}{v}\,\mathrm{tg}\,\Theta\right)^2 = \varepsilon_r \left[\left(1 + \frac{1}{\varepsilon\mu_z} \cdot \frac{a^2}{R^2 - a^2}\right) 2\ln\frac{R}{a}\right]^{-1}. \qquad (9)$$

The dependence (9) characterizes the dispersion properties of the system at low frequencies. Analysis of it shows that increase in the thickness of dielectric layers influences the retardation (reduces the phase velocity). Comparing (8) and (9), it can be concluded that with low frequencies just as in the case of high frequencies, dispersion occurs, the course of disperion in these extreme cases being normal.

The dispersion curves plotted in Fig.2 give a more complete picture of the spiral in a waveguide with dielectrical discs ($\mu = 1$). These graphs were obtained through solving equation (7) in case of the following parameter values: $a/R = 0.5$; $q/l = 10$. Curves 1,2,3 correspond to $\varepsilon_1 = 100$, $\varepsilon_2 = 300$, $\varepsilon_3 = 500$. Rutile ($\varepsilon \approx 100$) and

barium titanate must be named among the materials having such dielectrical penetrances. In Fig.3 the retardation is represented as a function of the degree of anisotropy $\varepsilon_2/\varepsilon_r$. In calculation the following system dimensions were taken: $R = 1.0$ cm, $a = 0.5$ cm, $tg\theta = 0.064$. Graphs 1,2,3 correspond to $\lambda_1 = 10$ cm, $\lambda_2 = 40$ cm, $\lambda_3 = 90$ cm.

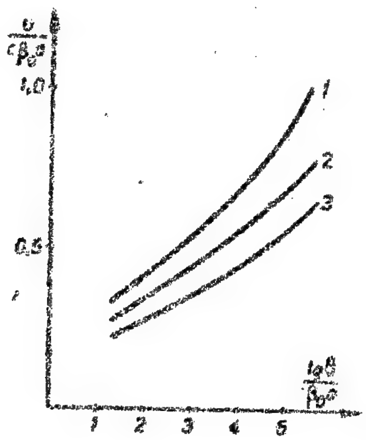

Fig.2

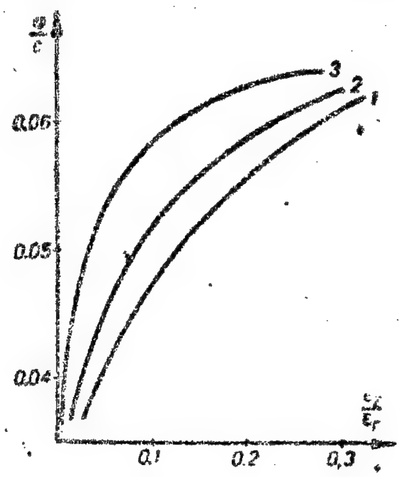

Fig.3

We write the expressions for the full stream of power flowing through inside spiral (P_1) and inside the anisotropic dielectric (P_2)

$$P_1 + P_2 = \frac{c}{8} \cdot \frac{\beta \cdot \beta_0}{\gamma_1^2} a^2 E_0^2 I_0^2 (\gamma_1 a) (\Pi_1 + \Pi_2) \cdot \qquad (10)$$

Here Π_1 and Π_2 correspond to the streams inside and outside the spiral and have the following form:

$$
\left.\begin{aligned}
\Pi_1 &= \left[\left(\frac{\gamma_1}{\beta_0}\operatorname{tg}\Theta\right)^2 - \frac{I_1^2(\gamma_1 a)}{I_0^2(\gamma_1 a)}\right]\left[1 - \frac{I_0(\gamma_1 a) I_2(\gamma_1 a)}{I_1^2(\gamma_1 a)}\right] \\
\Pi_2^* &= \frac{\gamma_1^2}{\gamma_2^2}\frac{\varepsilon_z^2}{\varepsilon_r}\frac{1}{\Delta_4^2}\left[\frac{1}{\gamma_2^2 a^2} - \frac{2}{\gamma_2 a}\Delta_3\Delta_4 - \Delta_3^2 + \Delta_4^2\right] - \\
&- \left(\frac{\gamma_1}{\beta_0}\operatorname{tg}\Theta\right)^2 \frac{1}{\Delta_1^2}\left[\frac{1}{\gamma_2^2 a^2} - \frac{2}{\gamma_2 a}\Delta_1\Delta_2 - \Delta_2^2 + \Delta_1^2\right]
\end{aligned}\right\} \quad (11)
$$

The curves of the resistance of coupling $K = \frac{E_0^2}{2\beta^2 P}$, shown in Fig.4 are plotted on the basis of the correlations (10) and (11). In calculation the following parameter values were preset: $a = 0.2$ cm, R = 1.0 cm. The curves 1,2,3 correspond to the values of the degree of anisotropy equal to 0.005, 0.01, 0.05. These values can be derived if the dielectrics spoken of above be employed as the diaphragm material.

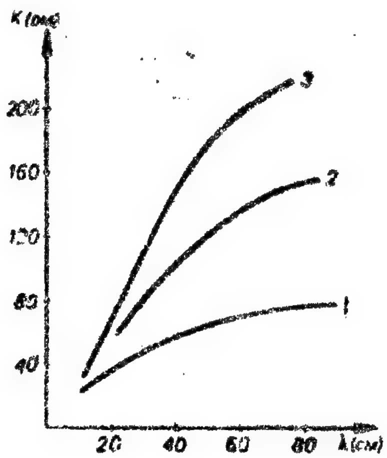

Fig.4

The losses in the spiral placed in a waveguide with anisotropic magnetodielectric can be represented as the sum of the loss in the walls of the waveguide, the loss in the helical conductor and the loss arising

on account of the presence of a magnetodielectric. The problems associated with losses in a coaxial spiral have been investigated to a considerable extent [8]. It is therefore sufficient to examine the additional losses which are formed in an anisotropic medium between the spiral and waveguide. Bearing in mind the complexity of analysis in the general case, we limit ourselves to the loss for the extremely important case of high frequencies.

The dispersion properties of the spiral with anisotropic magnetodielectric in approximation of high frequencies and $R \to \infty$ are described by equation (8). If the magnetodielectric has losses then the values β, ε_z, ε_r, μ_z, μ_r in (8) are complex:

$$\beta = \beta' + j\beta''; \quad \varepsilon_z = \varepsilon'_z + j\varepsilon''_z; \quad \varepsilon_r = \varepsilon'_r + j\varepsilon''_r;$$
$$\mu_z = \mu'_z + j\mu''_z; \quad \mu_r = \mu'_r + j\mu''_r.$$

Let us assume that the losses are small, i.e. $\varepsilon'_z \gg \varepsilon''_z$; $\varepsilon'_r \gg \varepsilon''_r$; $\mu'_z \gg \mu''_z$; $\mu'_r \gg \mu''_r$, and in addition, $\beta' \gg \beta''$. In this case the ratio of the imaginary part of the propagation constant β'' to its real part β' can be written as

$$\frac{\beta''}{\beta'} = \frac{1}{4}\left[\frac{\dfrac{\mu''_z}{\mu'_z} + \dfrac{\mu''_r}{\mu'_r}}{1 + \sqrt{\mu'_z\mu'_r}} + \frac{\dfrac{\varepsilon''_z}{\varepsilon'_z} + \dfrac{\varepsilon''_r}{\varepsilon'_r}}{1 + \sqrt{\varepsilon'_z\varepsilon'_r}} \cdot \sqrt{\varepsilon'_z\varepsilon'_r}\right]. \quad (12)$$

in which $\frac{\varepsilon''_z}{\varepsilon'_z} = \mathrm{tg}\,\delta_{\varepsilon_z}$ characterizes the dielectrical and $\frac{\mu''_z}{\mu'_z} = \mathrm{tg}\,\delta_{\mu_z}$,the magnetic losses in the direction of propagation; $\frac{\varepsilon''_r}{\varepsilon'_r}\,\mathrm{tg}\,\delta_{\varepsilon_r}$ and $\frac{\mu''_r}{\mu'_r}\,\mathrm{tg}\,\delta_{\mu_r}$ characterize the corresponding losses in the crosswise direction. From expression (12), it follows that with

$$\mathrm{tg}\,\delta_{\varepsilon_z} + \mathrm{tg}\,\delta_{\varepsilon_r} = \mathrm{tg}\,\delta_{\mu_z} + \mathrm{tg}\,\delta_{\mu_r} \quad \text{and} \quad \varepsilon'_z\varepsilon'_r > 1;\ \mu'_z\mu'_r > 1$$

the dielectrical losses always predominate over the magnetic.

Let us examine a moderating system in which the diaphragms are made of dielectrics $\mu'_z = \mu'_r = 1;\ \mu''_z = \mu''_r = 0.$; For this case by means of expression (6) we derive from (12)

$$\frac{\beta''}{\beta'} = \frac{1}{4}\,\frac{\varepsilon''}{\varepsilon'}\,\frac{q\,\varepsilon'\left[\frac{1}{\varepsilon'(l\varepsilon' + q)} + \frac{1}{l + q\varepsilon'}\right]}{1 + \sqrt{\frac{l\varepsilon' + q}{\varepsilon'(l + q\varepsilon')}}}. \qquad (13)$$

We compare (13) with the analogous correlation for the spiral in the isotropic dielectric (the latter can be derived from (12) with $\mu''_z = \mu''_r = 0;\ \varepsilon''_z = \varepsilon''_r;\ \varepsilon'_z = \varepsilon'_r$). With appropriate selection of l and q the losses in the spiral with the dielectrical diaphragms can apparently be made less than in a spiral surrounded by a uniform isotropic dielectric.

The expressions (12) and (13) permit calculating attenuation in the respective cases if the values of the dielectric and magnetic penetrances are preset, and also the tangents of the angle of losses of material.

A single viewpoint exists [9] concerning moderating systems made up of an anisotropic dielectric and moderating systems in the form of ribbed structure. By means of employing the conception of the phenomenon of complete internal reflection in such systems, it has been demonstrated that metallic ribbed structures are equivalent to a certain anisotropic dielectric. Its dielectric penetrance along the propagation direction has a finite value, but the penetrance in directions perpendicular to propagation are found infinitely large. Applying these findings to the system being explored (the spiral in a waveguide with dielectric diaphragms), the conclusion can be drawn that having, in the correlations developed for this device, assumed that $\varepsilon = \infty$, we derive the analogous expressions which describe a spiral placed in a waveguide with conducting diaphragms. After making this transition in equations (3) and (5), we arrive at the dispersion dependence for the spiral in a waveguide with conducting diaphragms:

$$\left(\frac{\gamma_1}{\beta_0} \operatorname{tg} \Theta \right)^2 = \frac{\gamma_1 \delta_2 I_1(\gamma_1 a)\left[\beta_0 \delta_4 I_1(\gamma_1 a) - \gamma_1 \delta_3 I_0(\gamma_1 a)\right]}{\beta_0 \delta_4 I_0(\gamma_1 a)\left[\gamma_1 \delta_3 I_0(\gamma_1 a) - \Gamma \delta_1 I_1(\gamma_1 a)\right]} , \quad (14)$$

in which

$$\delta_1 = J_0(\Gamma a) N_1(\Gamma R) - J_1(\Gamma R) N_0(\Gamma a) ;$$
$$\delta_2 = J_1(\Gamma a) N_1(\Gamma R) - J_1(\Gamma R) N_1(\Gamma a) ;$$
$$\delta_3 = J_1(\beta_0 a) N_0(\beta_0 R) - J_0(\beta_0 R) N_1(\beta_0 a) ;$$
$$\delta_4 = J_0(\beta_0 a) N_0(\beta_0 R) - J_0(\beta_0 R) N_0(\beta_0 a) ;$$
$$\Gamma^2 = \beta_0^2 - \left(\frac{\pi}{l} \right)^2 .$$

We note that these correlations can be derived directly through solution of the pertinent electrodynamic problem [11].

Shown in Fig.5 are the dispersion curves derived from equation (14) in case tqΘ = 0.1, R = 3.2 cm, ℓ = 0.65 cm. The graphs 1,2,3 correspond to a_1 = 0.8 cm, a_2 = 0.6 cm, a_3 = 0.4 cm. From the graphs it is evident that with the parameter values selected such a system possesses considerable dispersion which can be made both normal and abnormal.

One of the properties of this moderating system is the extremely advantageous energy distribution. Almost all the energy may be concentrated inside the spiral. The use of such systems will, consequently, produce an improvement of the conditions of the interaction of electromagnetic waves with beams of charged particles. The graphs of coupling resistance (for the system dimensions indicated above) are presented in Fig.6.

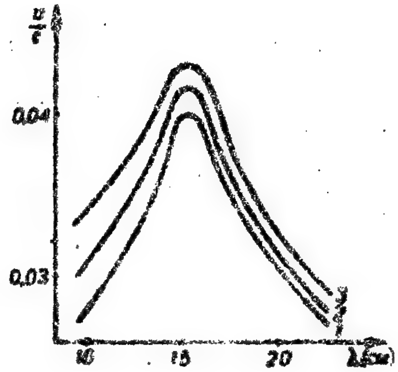

Fig.5

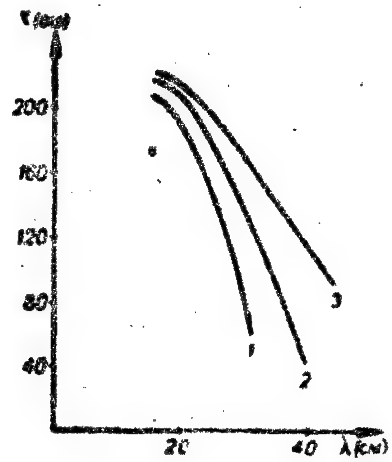

Fig.6

The losses in the system are formed of losses in the spiral and losses in the irised waveguide [8,11]. It must be added that certain qualitative characteristics of a spiral in an irised waveguide with metal diaphragms can be obtained by applying the method of equivalent circuits [5]. In particular, the circuit of Fig.7 can be used. The spiral is here represented in the form of a two-wire line. The cell of the irised waveguide corre-

-sponds to the parallel L,C circuit (consideration of the resonance properties of holes in the diaphragms complicates the circuit). This method has a number of shortcomings, among which it is essential to point out that the coaxial spiral approximates the two-wire line satisfactorily only in case of low frequencies.

In conclusion we note that the systems explored above are of interest for use in traveling wave tubes. The distinguishing property of tubes with such moderating systems can be a heightened amplification factor per unit of length with somewhat narrowed frequency band. The results of the investigation of a spiral in a waveguide partially filled with anisotropic dielectric can, to a certain extent, be generalized in a similar moderating system in which plasma occupies the place of the dielectric.

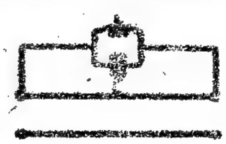

Fig.7

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Effect of the Form of Electrical Field in the Gun on the Noise Factor of Traveling Wave Tube

6

by A.A.Zyuzin-Zinchenko, V.M.Lopukhin, V.M.Vasil'yev

The results are presented of calculating the TWT noise factor depending on the form of the field in the electron gun. It is demonstrated that disturbances of the field near the cathode have an intense effect on the magnitude of the noise factor. With the transformation of the disturbing potential values from negative to positive, the noise factor passes through the extremum minimum. Characteristic integral curves of fluctuations of current and velocity in the TWT gun in case of various field disturbances W(x) are discussed.

Introduction

The TWT noise factor F is known to be called the value $F = 1 + \frac{\overline{U^2}_{s1}}{\overline{U^2}_{t1}}$, in which $\overline{U^2}_{s1}$ is the average squared value of the amplitude of the growing wave at the entrance to the helix caused by fluctuations of the density of the

convection current q and velocity of electrons v in the stream on the assumption that the signal in the system does not arrive; $\overline{U^2}_{t1}$ is the average value of the square of the amplitude of the growing wave at the entrance to the helix caused by fluctuation voltage of thermal noises.

The TWT noise factor determines its sensitivity. A considerable number of works [1 - 20,26,33] has been devoted to calculation of F.

The findings of experimental investigations of noise waves in electron streams are cited in works [17, 21-25]. These waves specify the periodic dependence of the TWT noise factor on the length of the drift space and the tube operating conditions.

The effect of the nonuniformity of cathode surface on the excitation of noise waves in the super high frequency amplifier is studied in article [5].

The minimal TWT noise factor is calculated in article [26] on the assumption that a certain quadripole which diminishes the noise in the stream has been placed between the helix and the electron gun.

Data on the low-noise TWT of the ten-centimeter band is given in the interesting work [27]. The minimal noise factor of this tube is equal to 4.8 db. Reduction of the noise factor is achieved on account of improving the des-

ign of TWT, which is characterized by low values of current and voltage of beam, and also losses in the helix.

Articles [28,29] which describe low-noise TWT with minimal noise factor of 3.5 db. are also extremely interesting. A tubular electron stream was used in these TWT; the noise factor strongly depended on the radial distribution of the gun potential.

Considerable attention has recently been paid to the parametric amplifiers, including also parametric amplifiers using electron streams [30,31]. According to preliminary findings, these amplifiers can possess an extremely low noise factor.

The TWT noise factor is a value which depends in a complex manner on a large number of parameters. The noise factor depends on the characteristics of the moderating system (retardation and impedance of the system), on the characteristics of the electron stream in the system (the magnitude of current, crosssection of stream, duty factor of helix with stream), on the geometry and electrical conditions of the gun and, finally, on the fluctuation processes at the cathode. The properties of a moderating system and the electron stream in a moderating system are satisfactorily accounted for by theory.

The chief difficulty is the calculation of conditions

close to the minimum of potential, where fluctuations are formed that excite waves in the electron stream. Strictly speaking, it is essential to calculate the minimum of potential conditions with consideration of statistics.

Investigation of the propagation of noise waves in the gun's electrical field which varies with coordinate also presents a certain difficulty.

The complexity of the problem led to the appearance of a number of works containing diverse approximations in computation of the TWT noise factor.

A critical survey of the works [1,3,4,6 - 16] in calculation of the TWT noise factor is given in [17]. It is demonstrated in this article that in case the space charge is absent, the fluctuations at the cathode cannot be considered "planar" but must be regarded as "point."

The estimates of the author of article [17], confirmed by experiment, indicate that the "point" character of fluctuations leads to the appearance of a large non-correlated background of 20 db. order in the expression for the noise factor. This background is connected with the higher harmonics excited in the stream.

It is also stated in article [17] that in the conditions of complete space charge when the fluctuations near the cathode can be considered "planar", the fluctuations

of current and velocity are without fail correlated. This statement has the character of a hypothesis and is in need of additional study.

The minimum of potential does not change the velocity fluctuations. In article [19] an attempt is made to calculate the compensating current fluctuation near the potential minimum.

In article [20] model studies of random processes close to the potential minimum by means of the Monte Carlo method are carried out on the assumption of a complete space charge and "planar" fluctuations at the cathode. The calculation of average values for current and velocity fluctuations, found for 3000 partial intervals of time Δt (each interval is assumed equal to $\Delta t = 10^{-12}$ sec.), showed the absence of correlation of current and velocity fluctuations in the plane $x = 1.2\ x_m$, in which x_m is the distance of the potential minimum from the cathode. The depression factor of the shot effect fluctuation $F^2(\omega)$ at the potential minimum, and also the min $F(\omega)$ were calculated. For the concrete tube type studied and fixed operating conditions F^2 and min F have a minimum at $f = \frac{\omega}{2\pi} = 2500$ Mc. The calculations were made by means of an electronic computer.

Another group of problems is examined in this article.

For the calculation of the noise factor of concrete TWT with a known gun geometry and electrode potentials, it is necessary to integrate the equation of the electron travel in the gun, taking into account the gun's real geometry and its electrical conditions.

In a number of works [1,2,7] this problem is solved by means of the Llewellyn formulae which are applied, however, only in a one-dimensional problem, whereas in real TWT guns which usually have a series of diaphragms, to consider the field one-dimensional is impossible.

The conception of the gun's electrical length L_{el} is used in some articles [18]:

$$L_{эл} = \int_0^z \beta_p(z)\, dz,$$

in which $\beta_p = \frac{\omega_p}{v_0}$ is the plasma wave number of electrons (ω_p is the plasma frequency, v_0 is the average velocity of electrons). This value is convenient for qualitative description of the behaviour of the TWT noise factor in dependence on conditions. The introduction of this conception is legitimate, however, only under the condition $\frac{1}{v_0}\frac{dv_0}{dz} \ll \beta_p$, which cannot be fulfilled in certain sections of real guns.

The purpose of this study is to clarify the effect

forms of the electrical field of the gun have on the TWT noise factor. It is presumed that conditions of a complete space charge occur. The current and velocity fluctuations in the virtual cathode are considered planar, so that only a fundamental wave is excited in the stream.

The correlations of current and velocity fluctuations in the virtual cathode are formally taken into account as is done in the works [9, 15].

The problem is solved for a cylindrical electron stream (an infinite focusing magnetic field is assumed) in a single-velocity approximation.

<u>Calculation of TWT Noise Factor</u>

In calculating the TWT noise factor F we proceed from the expressions [3]

$$F-1=\frac{C}{kT\Delta f Z}\left|(a_s+b_s)\frac{v_0 v}{\eta}-jq\frac{2U_0C}{q_0}(a_s b_s-4QC)\right|^2. \quad (1)$$

in which $C=\sqrt[3]{\frac{ZI_0}{4U_0}}$; $k=1{,}38\cdot10^{-23}$ erg/degrees; T is the temperature at the helix entrance in absolute degrees ($T = 300°$ K); Δf is the pass band of the intermediate frequency amplifier in cycles per second; Z is the longitudinal impedance of the helical line in ohms; $\eta=\frac{e}{m}=1{,}76\cdot10^{11}\frac{K}{KZ}$; v_0 is the average velocity of electrons in the stream corresponding to potential U_0, so that

v_0(m/sec) = 5.95 x $10^5\sqrt{U_0}$ (where U_0 is in volts); v and q are variable components of the velocity of electrons and density of convection current at the helix entrance; $j=\sqrt{-1}$; I_0 is the full current in the stream; q_0(a/m^2) is the constant component of the density of convection current in the stream; δ_2 and δ_3 are the second and third roots of the dispersion equation

$$\delta^2 = \frac{1}{(-b+jd+j\delta)} - 4QC,$$

where d is the parameter determining the attenuation of waves in a cold system (lower than the everywhere adopted d = 0.25), b is the parameter of the relative velocity of electrons and Q is the parameter of the space charge [1].

The expression for the potential V_k of each of the three direct waves is written in the form:

$$V_k = V_{k0} \exp(-j\beta_e + \beta_e C\delta_k) z; \quad k = 1,2,3;$$
$$\delta_2 = x_2 + jy_2; \quad \delta_3 = x_3 + jy_3,$$

in which x and y are the real and imaginary components of the roots of the dispersion equation; V_{k0} is the potential wave amplitude.

The roots δ_2 and δ_3 are characterized in that $x_2 < 0$ and $x_3 \simeq 0$, i.e. they correspond to attenuating and non-growing waves.

Expression (1) is correct in the following assumptions: electrons travel only along axis z; in the stream are propagated three direct waves corresponding to one and the same distribution of the electromagnetic field in cross section, i.e. waves of higher orders are absent in the stream; the terminal cross section of the electron stream is taken into account owing to the dependence of Q on the stream and helix radii [1].

We transform expression (1). Everywhere below in the integration of equations of electron travel in the zone of the gun or space of the drift, we will assume that the variable components of the fluctuation convection current q and velocity v have the form:

$$q(z,t) = \hat{q}(z)\, e^{-j\int \beta_e dz}\, e^{j\omega t}; \quad v(z,t) = \hat{v}(z)\, e^{-j\int \beta_e dz}\, e^{j\omega t},$$

in which $\beta_e = \omega / v_0$. (In future we omit the "tilde" marks over the variable components $\hat{q}$ and $\hat{v}$.)

Assuming further the rightness of the theory of small amplitudes, which is fulfilled well for noise signals, we have:

$$v = -\frac{v_0^2}{j q_0 \omega} \cdot \frac{dq}{dz}, \qquad (2)$$

in which $v_0 = v_0(z)$ is the constant velocity component in m/sec.; q_0 is the constant component of convection

current density in a/m^2; $\omega = 2\pi f$ is the angular frequency.

We introduce the dimensionless coordinate $x = \frac{z}{l_0}$, $z(x)$, $l_0 = 10^{-3}$ m.* (*Introduction of x is equivalent to measurement of the distance along the stream in millimeters.) Then (2) assumes the form:

$$v = -\frac{v_0^3}{I q_0 \omega} q' \cdot 10^3, \qquad (3)$$

where

$$q' = \frac{dq}{dx}.$$

Substituting (3) in (1), after transformation we have

$$F - 1 = A q^2 - B q q' + E q'^2 |_{x=L}, \qquad (4)$$

in which

$$A = \frac{4 C^4 U_0^2 \Delta_1}{k T \Delta f Z q_0^2}; \quad B = \frac{8 C^3 v_0 U_0^2}{k T \Delta f Z q_0^2 \omega} \cdot 10^3 \Delta_2;$$

$$E = \frac{8 C^2 \eta U_0^3}{k T \Delta f Z \omega^2 q_0^2} 10^6 \Delta_3; \; \Delta_1 = (y_2 y_3 + 4 Q C)^2 + x_2^2 y_3^2;$$

$$\Delta_2 = x_2 (y_3^2 - 4 Q C), \quad \Delta_3 = x_2^2 + (y_2 + y_3)^2.$$

Here L is the distance from the cathode to the entrance in the helix. All other symbols have the usual sense referred to above. The dimension values (U_0, k, T, f, Z, q_0, v_0, η, ω) are calculated in the MKS system, the coordinate x is taken in mm.

From formula (4) it is clear that the noise factor F depends on the beam, helix parameters, and also on the values q and q' at the entrance to the helix, i.e.

with $x = L$.

For the calculation of q and q', it is necessary to integrate the equation of electron travel in the gun with potential $U = U(x)$, which for real guns is taken by means of an electrolytic bath.

Integration of Equations of Electron Travel in the Gun

Joint solution of the equations of the electromagnetic field and the equations of electron travel in the beam in the assumption of small amplitude theory, leads to the equation [25]

$$q'' + 3\frac{v'_0}{v_0}q' + \frac{\omega_p^2}{v_0^2}q = 0. \qquad (5)$$

in which q is the variable component of convection current density in a/m^2; $q' = dq/dz$; $q'' = d^2q/dz^2$; $v_0 = v_0(z)$ is the constant component of velocity of electrons; $v'_0 = d\ v_0/dz$; $\omega_p = \omega_0 \cdot \alpha_0$; ω_0 is the plasma frequency; $\alpha_0 = \alpha_0(\xi)$ is given by the work graph [3], in which $\xi = \beta_e b = \frac{\omega}{c_0} b$; ω is the angular frequency; b is the radius of the electron stream; v_0 is the average stream velocity.

Equation (5) is approximate, derived in the assumption $\omega_p \ll \omega$, which is usually well fulfilled; we will assume that the electrons travel only along axis z.

the finitness of the stream cross section is taken into account by the function $a_c(\xi)$.

In equation (5) $v_0 = v_0(z)$ should be calculated with consideration of the constant space charge component.

Let us examine the conditions of cathode current limitation by the space charge. At the same time the potential minimum is formed near the cathode. We place the beginning of coordinate $z = 0$ in the plane of the potential minimum. The constant component of electron velocity in cross section $z > 0$ close to the cathode is determined by the expression:

$$v_0^2 = v_{0c}^2 + 2\frac{e}{m}U(z), \qquad (6)$$

in which $v_{0c} = \sqrt{\frac{\pi k T_c}{2m}}$ is the average velocity of electrons in the minimum of potential, calculated for the Maxwell distribution of electrons close to the cathode in velocities, $k = 1.38 \cdot 10^{-23}$ erg/degree, T_c is the temperature of the cathode (for $T_c = 1030^\circ$, v^2_{0c} corresponds to 0.07 ev), $U(z)$ v is the potential determined by the equation / 36/:

$$q_0 z^2 = 10^{-6}(2{,}33\,U^{\frac{3}{2}} + 1{,}84\,U), \qquad (7)$$

in which z is the distance from the potential minimum in meters; q_0 is the constant component of convection current

density in a/m^2.

Introducing just as before, the dimensionless coordinate $\chi = z/l_0$, where $l_0 = 10^{-3}$ m, we write (7) in the form:

$$c_0 x^2 = 2{,}33\, U^{\frac{3}{2}} + 1{,}84\, U. \qquad (8)$$

Equation (8) is a generalization of the "law $3/2$" in the case when the initial velocities of electrons in the potential minimum are taken into account. Equation (8) is correct only in the extremely small distance $\chi < \chi_1$ from the potential minimum in that zone where the field is one-dimensional. For definiteness we will assume $\chi_1 = 0.2b$, where b is the stream cross section radius. In the space between the planes $\chi = \chi_1$ and $\chi = L$ ($\chi = L$ corresponds to the helix beginning), we will, for definiteness, set potential $U(\chi)$ in the form of the curve plotted in Fig.1. Potential distributions of this type are obtained in three-electrode guns of the kind pictured in the same drawing, with definite potential values on the electrodes [21]. In the interval $0.2\,b < \chi < L$, the curve $U(\chi)$ is so selected that with $\chi = 0.2b$ it changes over to the curve given by equation (8). The selection of potential in the interval $0.2b < \chi < L$ is not essential, since the purpose of further calculations is to establish the dependence of the noise factor on disturbance of potential, with

variation in wide limits of parameters characterizing this disturbance.

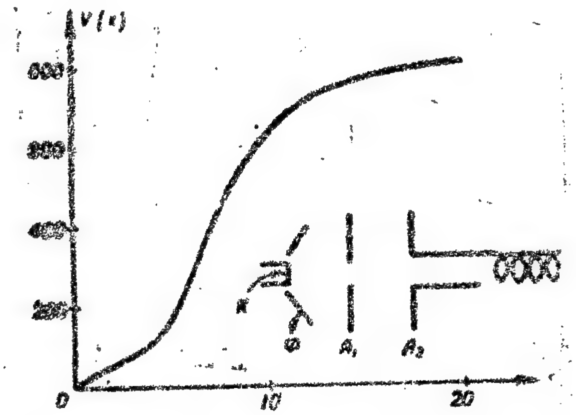


Fig. 1 Undisturbed potential in gun V (x) and circuit of three-electrode TWT gun.

With consideration of (6), equation (5) assumes the form:

$$q'' + 1{,}5\,\frac{U'}{U_0 + U}\,q' + 9{,}5\cdot 10^{-1}\,\frac{q_0\,\omega_q^{2}(\xi)}{(U_0 + U)^{3/2}}\,q = 0, \qquad (9)$$

in which

$$U_0 = 0{,}07; \quad q' = \frac{dq}{dx};$$

$$q'' = \frac{d^2 q}{dx^2};$$

$$U(x) = \begin{cases} x^2 q_0 = 2{,}33\, U^{\frac{3}{2}} + 1{,}84\, U & \text{for } 0 < x < x_1 \\ \text{is given by curve Fig. 1} & \text{"}\ x_1 < x < x_2 \\ U_0 = \text{const} & \text{"}\ x_2 < x < L \end{cases}$$

χ_2 is the gun length from the cathode to the entrance into the drift cylinder;

L is the distance from the cathode to the entry helix;

U_o is the helix potential; q_o and α_o have the former sense.

Equation (9) should be solved with definite boundary conditions in the virtual cathode $\chi = 0$.

In accordance with work [15], we assume that in the cathode are excited three waves of convection current q_1, q_2 and q_3 with three types of initial conditions:

$$\begin{aligned} &\text{I. } \sqrt{1-k}\, q_1(0) \neq 0; \quad q'_1(0) = 0; \\ &\text{II. } q_2(0) = 0; \quad \sqrt{1-k}\, q'_2(0) \neq 0; \\ &\text{III. } q_3(0) = q_1(0)\sqrt{k\varkappa}; \quad q'_3(0) = q'_2(0)\sqrt{k\varkappa}, \end{aligned}$$

in which $0<k<1$, $0<\varkappa<1$ are coefficients characterizing correlations in the virtual cathode.

The values $q_1(0)$, $q'_2(0)$ are expressed by formulas [35,36]:

$$\left.\begin{aligned} S_0^2\, q_1^2(0) &= \Gamma^2\, 2 e I_0\, \Delta f \\ q'_2(0) &= \frac{q_0\, \omega\, v_2(0)}{v_0^2(0)} \cdot 10^{-2} \\ v_2^2(0) &= (4-\pi)\, \eta \frac{k\, T_c}{I_0}\, \Delta f \end{aligned}\right\}, \qquad (10)$$

in which $S_o(m^2)$ is the area of the stream cross section; $I_o = S_o q_o$ is the full stream current; Tc is the cathode temperature; Δf is the band width of the intermediate frequency amplifier in cycles per second; Γ^2 is the depression factor of shot effect fluctuations of current at

the minimum of potential. According to [16] this factor in centimeter waves has a value of the order of 0.6 - 0.8 depending on the cathode operating conditions, density of emission current and cathode temperature.

The waves q_1 is excited by current fluctuations in the virtual cathode, q_2 by velocity fluctuations, and q_3 by correlated fluctuations of current and velocity. Taking into account the linearity of equation (9), one can write:

$$q_3(x) = q_1(x) + q_2(x).$$

To each of the three waves corresponds the noise factor F_i ($i = 1,2,3$), calculated by the formula

$$F_i - 1 = A\, q_i^2 - B\, q_i\, q_i' + E\, q_i'^2, \tag{11}$$

where q_i is calculated at the entrance to the helix $q_i = q_i(L)$.

The complete noise factor F assumes the form:

$$F - 1 = (1 - k)(F_1 - 1) + (1 - k)(F_2 - 1) + k\varkappa(F_3 - 1). \tag{12}$$

With $k = 0$ correlations are absent, with $k = 1$ correlations are complete, factor $\varkappa < 1$ characterizes the depression of the correlated wave at the potential minimum.

From (11) and (12) it follows that the noise factor F depends on the correlations in cathode $k, \varkappa$ of helix and current (A,B,E) parameters and the forms of fields

in the electron gun, which determine the $q_1(x)$, $q'_1(x)$ behaviour and consequently, $q_1(L)$ and $q'_1(L)$.

The problem of this study is the calculation of the variable components $q_1(x)$ and $q_2(x)$, and also the TWT noise factors F_1 and F_2 in case the electrostatic field in the gun $U(x)$ varies in wide limits. The values F_1 and F_2 obtained from (11) correspond to non-correlated excitation of noises by current and velocity fluctuations. The correlation of current and velocity fluctuations at the potential minimum was not taken into account. Its calculation can be done formally by means of formula (12), whereupon for computation of the correlation factors k and $\varkappa$, it is necessary to take into account conditions in the cathode -potential minimum space.

Let us assume that the distribution of potential in the gun has the form:

$$U(x) = V(x) + W(x),$$

in which $V(x)$ is the potential (Fig.1) corresponding to one of the possible conditions of the three-electrode TWT gun; $W(x)$ is the function determined by the expression:

$$W(x) = \begin{cases} 0 & \text{for } 0 < x < x_1 \\ D\dfrac{(x-x_1)^2(x-x_2)^2}{\bar{\beta}^2(x_2-\bar{\beta})^2} e^{-\bar{\gamma}(x-\bar{\beta})^2} & \text{for } x_1 < x < x_2. \\ 0 & \text{for } x_2 < x < L \end{cases} \qquad (13)$$

+ where $\chi_1 = 0.1$; $\chi_2 = 22$, parameters D, $\bar{\gamma}$, $\bar{\beta}$ assume a number of values.

From expression (13) for $W(\chi)$ it follows that D is proportional to the amplitude of the disturbed field, $\bar{\beta}$ is equal to the distance from the cathode (in mm) at which the disturbing field is maximal, $\bar{\gamma}$ characterizes the width of the disturbing field W (in the plane $\chi - \bar{\beta} \sim \bar{\gamma}^{-\frac{1}{2}}$ the disturbing field drops e times). It is evident that by varying D, $\bar{\gamma}$ and $\bar{\beta}$ the form of the field of TWT gun can be modified in wide limits. Practically disturbance of the (12) kind can be created by placing in the gun one or several additional diaphragms with definite apertures and potentials. Shown in Fig. 2,a are graphs for $q_1(\chi)$ and $q_2(\chi)$, $q'_1(\chi)$ and $q'_2(\chi)$, in which $q_1(\chi)$ and $q_2(\chi)$ represent the results of the integration of equation (9) with boundary conditions of the I or II type in case of U = V + W.

Adopted for definiteness in the integration of (9) are:

$$q_0 = 10^3 \frac{a}{м^2}; \; I_0 = 500 \cdot 10^{-6} a; \quad U_0 = 800 \, в.$$

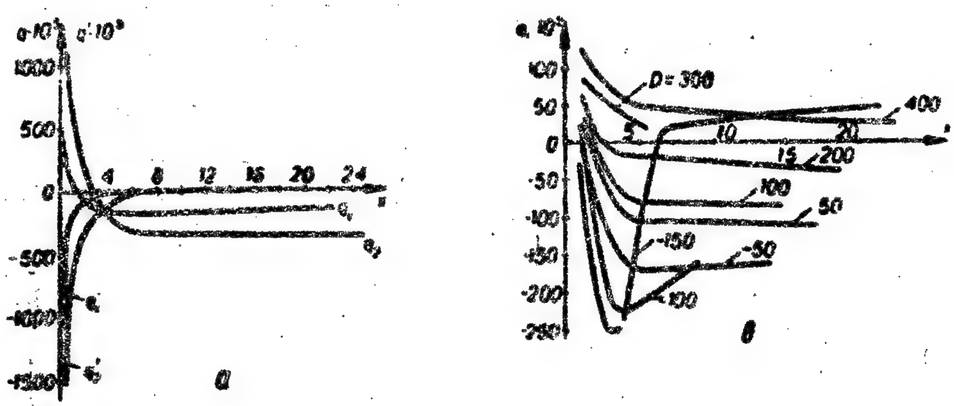
The boundary conditions for $q_1(0)$ and $q'_2(0)$ are calculated by means of formula (10) in which was adopted:

$$S_0 = \pi b^2, \; b = 4 \cdot 10^{-4} \; м,$$

$$\Gamma^2 = 0{,}7, \quad \Delta f = 2 \cdot 10^8 \; гц,$$

$$\omega = \frac{2\pi c}{\lambda}, \; c = 3 \cdot 10^8 \; м/сек, \; \lambda = 0{,}08 \; м.$$

+ 1 - cycles per second
2 - m/sec



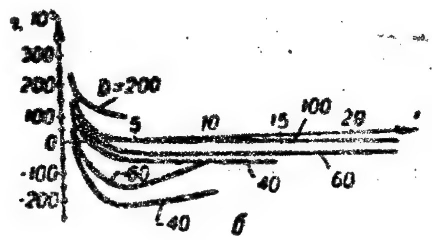


Fig.2. Dependencies $q_1(x)$; $q_2(x)$; $q'_1(x)$; $q'_2(x)$; $0.1 \le x < 22$: a) $\beta = 5$; $\gamma = 0.1$; $D = -25$; б) $\beta = 3$; $\gamma = 0.01$; в) $\beta = 5$; $\gamma = 0.01$

The forms of integral curves $q_1(x)$ and $q_2(x)$ close to the virtual cathode are shown in Fig.3. From this drawing

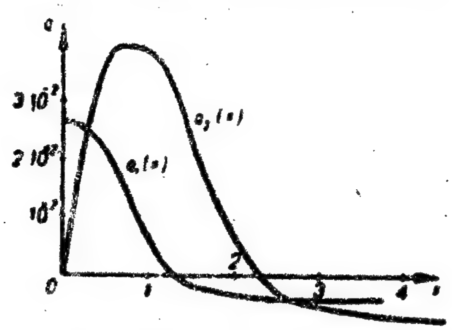


Fig.3 Dependencies $q_1(x)$ and $q_2(x)$ close to the virtual cathode.

it is clear that near the virtual cathode the curves $q_1(x)$ and $q_2(x)$ experience intense disturbance, then pass through zero and are further uniformly varied to point $x = 22$; for $x > 22$ the curves $q_1(x)$ and $q_2(x)$ vary periodically

with the coordinate, with a period of $\frac{2\pi}{\beta_p}$, where $\beta_p = \frac{\omega_c}{v_0} a_0 \tau$| For the conditions examined $\beta_p = 2.65 \cdot 10^{-2}$ mm^{-1}, Fig. 2 indicates that the space charge near the virtual cathode suppresses the current and velocity fluctuations so that for a point sufficiently remote from the cathode (for example, $X = 22$), $x = 22$), $|q_1(0)| \gg |q_1(x)|$ и $|q_2(0)| \gg$ $\ll |q_2(x)|$.

In Fig. 2,b and c are given integral curves $q_1(X)$ and $q_2(X)$ for the interval $1 < X < 22$ with various values of the parameters $D, \bar{\beta}, \bar{\gamma}$ of function $W(X)$. Fig.2, b and c show that the integral curves $q_1(X)$ qualitatively have an identical form under various disturbance conditions. With the rise of D from negative values to positive, the curves $q_1(X)$ rise from the zone $q(X) < 0$ upward, approaching axis X. All the curves have a minimum, extremely sloping for $D > 0$ and more pronounced for $D < 0$. These characteristics of the behaviour of the curves is especially evident at low $\bar{\beta}$ (for example $\bar{\beta} = 3$). Variation of $\bar{\gamma}$ influences the behaviour of the integral curves to a lesser extent than change of $\bar{\beta}$ does. The value of $\bar{\beta}$ is determined by the cross section in which the diaphragm disturbing the field is placed. The graphs of Fig.2, consequently, indicate that the diaphragm intensely disturbs the integral curves $q_1(X)$ and $q_2(X)$ if it is placed near the cathode, for example, at a distance which corresponds to $\bar{\beta} = 3$ mm. The curves

$q_2(X)$ qualitatively vary in dependence on $\bar{\beta}, \bar{\gamma}$ and D just the same as $q_1(X)$.

Considering that the noise factor F is increased with the rise of $|q(X)|$ and $|q'(X)|$ at the entrance to the helix, reduction of the noise factor can be expected in the case when $q(X)$ and $q'(X)$ in the gun are small, i.e. the integral curves $q_1(X)$ and $q_2(X)$ are close to axis X.

It follows from Fig.2 that integral curves with rise of D at first approach axis X from below ($q<0$), and then recede from axis X upwards ($q>0$). This means that with fixed $\bar{\beta}$ and $\bar{\gamma}$ the TWT noise factor must have a minimum depending on D.

Integrating equations (9), we calculate $q_i(L)$ and $q'_i(L)$ ($i = 1.2$) and further by formula (11) find the noise factor of the tube F_1 depending on paramters that characterize field disturbance. The chief role in determining the noise factor is played by F_2 which is 10 to 100 times greater than F_1.

Plotted in Fig.4 is the dependence of noise factor F_2 on parameter D in proportion to the disturbing field's amplitude, with different values of $\bar{\beta}$ and $\bar{\gamma}$.

In all more than 150 equations were integrated that correspond to various disturbing fields in the TWT gun. The integration was done by means of a high speed electronic

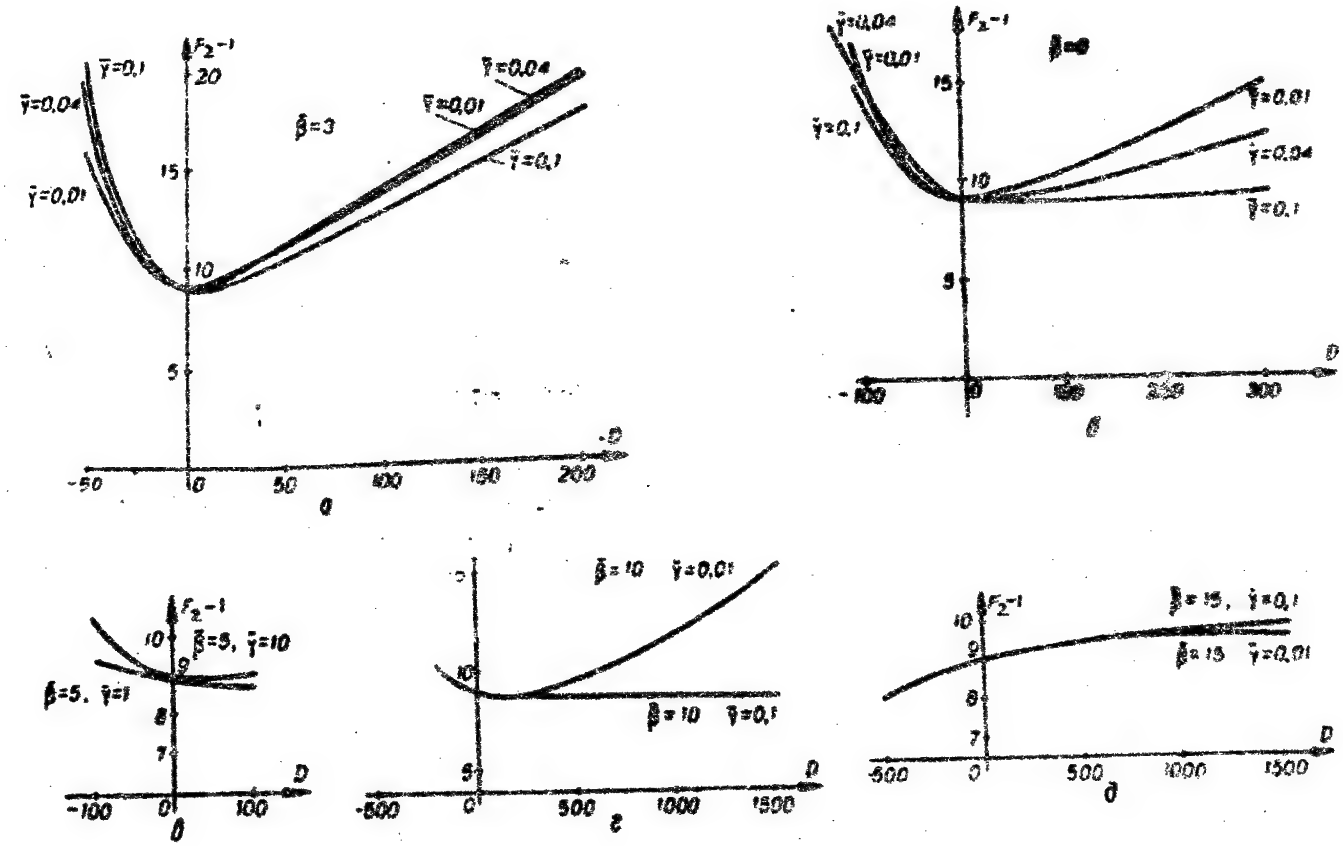


Fig.4. Dependencies $F_2(D)$: а) $\bar\beta = 3$; б) $\bar\beta = 5$; в) $\bar\beta = 5$; г) $\beta = 10$; д) $\beta = 15$.

computer ATsVM-2 at the Moscow University computing center.

Conclusions

On the grounds of the Fig. 4 graphs, such conclusions can be drawn:

1. The dependence of $F_2(D)$ is manifested most intensely if $\bar{\beta} = 3$ and is least perceptible if $\bar{\beta} = 15$, which corresponds to the circumstance that field disturbance near the cathode has a more intense effect on the trajectories of electrons than disturbance remote from the cathode.

2. All $F_2(D)$ curves at $D = 0$ intersect at one point $F_2 = 9$; this value corresponds to the noise factor of the concrete TWT examined in the absence of a disturbing field.

3. With $\bar{\beta} = 3$ and $\bar{\beta} = 5$, i.e. in the case when the field is disturbed sufficiently close to the plane of the cathode ($x = 0$) variation of parameter $\bar{\gamma}$ has little effect on the form of curve $F_2(D)$.

4. With $\bar{\beta} = 3$, $\bar{\beta} = 5$ for all $\bar{\gamma}$ and with $\bar{\beta} = 10$ for $\bar{\gamma} = 0.01$, which corresponds to a sufficiently sloping curve of field disturbance, $F_2(D)$ has a minimum lying close to the value $F_2(0) = 9$. This signifies that in the concrete tube examined the field disturbances determined by formula (13) lead to an increase of its noise factor. The tube is practically optimal in field form. This con-

clusion is in accord also with the results of work [21] in which it is stated that field distribution in the gun close to that given in Fig. 1 is most favorable from the viewpoint of low noise. Smooth growth of potential in the gun from cathode to helix is characteristic for this field.

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The Use of Phase Preselections of Signal for Raising the Noiseproof Feature of Radiotelegraph Communication Systems

\# 7

by Yu.N.Babanov

The question examined is the application of the method of phase preselections in radiotelegraphic communication systems for the purpose of raising the noiseproof feature with respect to single pip noise. Experimental data are given.

Introduction

Many varied methods of protecting communication systems from pulse noises have been elaborated in detail at present. The stretching of these noises in time is one of the methods of protection from noises whose level is below the level of the useful signal. With stretching lowering of the noise level occurs, owing to which the signal/noise ratio is increased at the output of the communication system receiving device. This method, however, has a substantial defect: the devices that stretch noises

simultaneously distort the useful signal (phase distortions).

The idea of group transmission of signals proposed by D.V.Ageyev in 1938 [1] is employed in this study. In the method proposed ordinary telegraph signals which must be sent in a communication line are stretched beforehand in time by the creation of phase preselections. Due to these preselections several transformed stretched telegraph sendings will be transmitted at any moment of time, which is the chief characteristic of the method of group transmission of elementary signals. In the receiver the received signal is passed through a device with parameters so chosen as to compensate the phase distortions of the useful signal. Owing to the compensation of phase distortions every telegraph sending assumes its original form at the output of the receiving set, somewhat delayed in time.

Pulse noises entering the receiver together with the useful signal are, during passage through the compensating device, stretched in time, since in distinction from the signal, they do not have phase preselections.

<u>The Method of Phase Preselections</u>

Shown in Fig.1 is the block diagram of a device which accomplishes phase preselections. The device is a system of cells connected in parallel, each of which

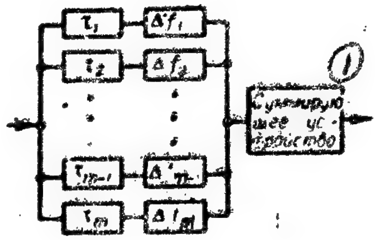

Fig.1. Block diagram of device which produces phase distortions of the signal.

a-summation device

consists of a filter with band Δf_i and a quadripole which realizes the signal delay in time τ_i. Inasmuch as each filter passes only part of the signal spectrum Δf_i ($i = 1, 2, 3 \ldots m$) and the delay τ_i ($i = 1, 2, 3 \ldots m$) is varied, the signal at the device output will be stretched in time. If the telegraph signal (Fig.2,a) be supplied to the input of such a device, then the device will stretch each elementary sending. The new sending duration is $\xi_1 \cong (\tau_i)_{max} - (\tau_i)_{min}$, in which $(\tau_i)_{max}$ is the greatest, and $(\tau_i)_{min}$ is the least delay. In Fig 2 b, 2 c and 2 d, three such stretched sendings are shown as examples. For graphic illustration, they are represented separately one from the other. At the output of the device in reality each such sending will be partly imposed on by $n - 1$ stretched sendings following behind it in a similar manner. The magnitude $n - 1$ will be determined by how much this signal is stretched by the

device, i.e. what its new duration ξ_1 will be. At any moment of time t_1, the instantaneous signal value at the device output is: $V_{out}(t_1) = \sum_{k=1}^{n} v_k(t_1)$, in which $v_k(t_1)$ is the instantaneous value of the stretched sending k at the time moment t_1. Due to compensation of phase preselections, the signal receives the original form Fig.2,e at the output of the receiving device.

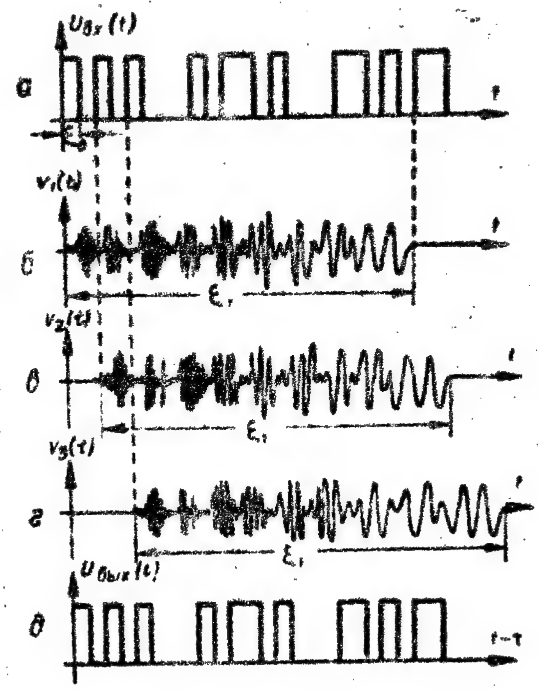

Fig.2. Schematic of phase preselection method realization: a - input signal, b,c,d transformed first, second and third telegraph sendings of the input signal; e - output signal.

The duration of a single noise at the receiving set output is $t_n \cong (\tau_1')_{max} - (\tau'_1)_{min}$, in which $(\tau_1')_{max}$

† and $(\tau'_i)_{min}$ are the greatest and the least constant times of the totality of constant times τ_i' ($i = 1,2,3 \ldots m$) of the compensating device's delaying quadripoles. Whereupon, with k times increase of the noise duration, the average level (within the limits of the new duration) is reduced roughly k times.

The parameters (Δf_i) and (τ_i) $i = 1,2,3 \ldots m$) of the transmitter's stretching device must be so selected that the top cutoff frequency of the filter with number i might coincide with the bottom cutoff frequency of the filter with number $i + 1$, in which $i = 1,2,3 \ldots m - 1$, and the equality $\sum_{i=1}^{m} \Delta f_i = \Delta F$, is fulfilled, where ΔF is the band width of the frequency necessary for non-distorted transmission of the elementary sending (refers to frequency distortions). Finally, the constant times of the delaying quadripoles must satisfy the equality $\tau_{i+1} = \tau_i \mp T \cdot \xi_0 \cdot m \quad (i = 1, 2, 3, \ldots m - 1)$ in which ξ_0 is the duration of the unstretched elementary sending.

Parameters of the compensating device in the receiver are selected taking the following into consideration: (a) the filter with number i ($i = 1,2,3 \ldots m$) of compensating device must be identical to the filter with number i ($i = 1,2,3 \ldots m$) of the stretching device; (b) the constant times must satisfy the equality: $\tau_1 + \tau_1' = \tau_2 + \tau_2' = \ldots = \tau_m + \tau_m'$

$= \tau - \tau_s = \tau_0 = \text{const.}$

If all these requirements are met the communication system as a whole will not distort the signal passing through it and at the same time will stretch the pulse noises coming into the receiver.

Analysis of Distortions

Departures from meeting the conditions formulated above for the ideal system create distortions. It is, therefore, necessary to determine clearly the departures from meeting the mentioned conditions, that are permissible for reliable and correct operation of the final device. For this purpose, we remind about the following characteristics of the operation of telegraphic communication systems [2,3]: (a) before landing in the terminal device, the output signal is limited in maximum and minimum; (b) the performing mechanisms of the terminal device possess correcting capacity μ (for synchronous apparatus $\mu \geqslant 35\%$ and for start-stop $\mu \geqslant 25\%$).

Residual Phase Distortions

To obtain a non-distorted signal at the system output, it is, other conditions being fulfilled, essential that the equality $\tau_i + \tau_i' = \tau_0$ is fulfilled for any cell with number i (i = 1,2,3 ...μ). Practically another correlation occurs: $\tau_i + \tau_i' = \tau_0 \pm \Delta\tau_i$. The errors $\Delta\tau_i$ depend on inaccuracy in making the delaying quadripoles, instabi-

lity of the elements entering their circuits and so forth.

A detailed theoretical analysis [4] (carried out on the assumption that the equality $\tau_m + \tau_m' = \tau_0$, is fulfilled for the cell with number m and for all other cells occurs the correlation $\tau_i + \tau_i' = \tau_0 \pm \Delta\tau_i \; (i=1, 2, 3 \ldots m-1)$, , moreover, for every harmonic of the signal - a square wave with period T_0 - its own cell exists in the stretching and compensating devices) resulted in deriving the expression:

$$\Delta V(t) = \frac{4}{T_0} \sum_{i=1}^{m-1} (-1)^{i+1} \cdot \Delta\tau_i \cdot \sin \pi \cdot i \left(\frac{2t - \Delta\tau_i}{T_0} \right).$$

in which ΔV is a value characterizing the distortion of the form of the telegraphic sending; T_0 is the signal period; m is the number of cells. The worst case will occur when all $\Delta\tau_i$ will have identical sign. In this case:

$\Delta V_{max} = \frac{4}{T_0} \sum_{i=1}^{m-1} \Delta\tau_i$. If it is assumed that $\Delta\tau_i \leqslant 0,1 \frac{T_0}{i}$, , then after calculations we derive: $\Delta V_{max} \cong 0.6 A$, where A is the telegraphic sending amplitude. Such distortions can be considered permissible, if the limitation in maximum and minimum, and also the correcting capacity of telegraph sets μ be kept in mind. Although the distortion analysis indicated above was made for a signal of definite form, the analysis method itself and the findings, however, allow for

drawing the conclusion that the residual distortions will be permissible, if in the communication system for cell with number i the error is $\Delta\tau_{i\max} \leqslant T_i$ (where $1/T_i$ is equal to the top cutoff frequency of filters with number i in the stretching and compensating devices).

Frequency and Phase Distortions Introduced by Filter Systems

Shown in Fig.3 are the frequency and in Fig.4 the phase characteristics of the stretching and compensating devices, and also of the entire communication system as a whole. In order to evaluate the magnitude of distortions of a telegraphic sending, we make the following

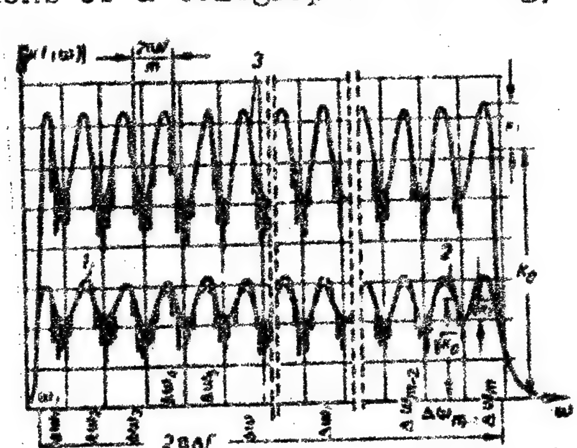

Fig.3. Frequency Characteristics: 1 - stretching device; 2 -compensating device, 3 -system as a whole.

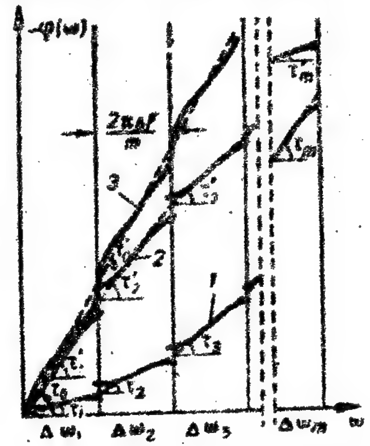

Fig.4. Phase Characteristics: 1 - stretching device 2-compensating device 3-system as a whole.

assumptions:(a) we will disregard the sharp dips in separate frequencies in the communication system's frequency

characteristic (as theoretical analysis and experiment have shown, signal distortions depending on the dips indicated will be practically imperceptible); (b) we will consider identical the band width of all filters, i.e.

$$\Delta\omega_1 = \Delta\omega_2 = \ldots = \Delta\omega_m = \Delta\omega.$$

Hence

$$m = \frac{2\pi\Delta F}{\Delta\omega};$$

(c) within the limits of the frequency band, from $\omega_{min} = \omega_1$ to $\omega_{max} = \omega_1 + 2\pi\Delta F$, we imagine the communication system's frequency characteristic in the form:

$$|K(j\omega)| \cong K_0 + K_1 \cos\frac{m}{\Delta F}\omega,$$

and the phase characteristic in the form:

$$\varphi(\omega) \cong -\tau_0\omega + \tau'_0 \sin\frac{m}{\Delta F}\omega,$$

in which K_1 is a value depending on the non-uniformity of the frequency characteristics of the stretching and compensating device, and τ'_0 is the non-linearity of the phase characteristics of filters;

(d) the input telegraph sending we represent in the general form $f_{in}(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} S(\omega)e^{j\omega t}\,d\omega,$

in which $S(\omega)$ is the spectral function of the telegraphic

sending. Then, employing the Fourier method, we derive [5]: $f_{out}(t) =$

$$\frac{1}{2\pi}\int_{-\infty}^{+\infty} S(\omega)\, e^{j\omega t}\left[K_0 + K_1 \cos\frac{m}{\Delta F}\omega\right] e^{-j\omega\tau_0}\, e^{j\tau_0' \sin\frac{m}{\Delta F}\omega}\, d\omega \cong$$

$$\cong K_0 I_0(\tau'_0) f_{вх}(t-\tau_0) + \left[\frac{K_1}{2} I_0(\tau'_0) + K_0 I_1(\tau'_0)\right] f_{вх}\left(t-\tau_0+\frac{m}{\Delta F}\right) +$$

$$+ \left[\frac{K_1}{2} I_0(\tau'_0) - K_0 I_1(\tau'_0)\right] f_{вх}\left(t-\tau_0-\frac{m}{\Delta F}\right) + \frac{K_1}{2} I_1(\tau'_0) f_{вх}\left(t-\tau_0+\frac{2m}{\Delta F}\right) -$$

$$-\frac{K_1}{2} I_1(\tau'_0) f_{вх}\left(t-\tau_0-\frac{2m}{\Delta F}\right).$$

Here $I_0(\tau'_0)$ is a Bessel function of the first kind, zero order, and $I_1(\tau'_0)$ is a Bessel function of the first kind, first order. (As is evident from the derived expression and Fig.5), the output telegraph sending represents the sum of the fundamental pulse, amplified $K_0 I_0(\tau'_0)$ times, and four "echoes". The most intense distortions depend on the non-linearity of the phase characteristic. Actually, with the growth of τ'_0, the amplitude of the fundamental pulse is very rapidly reduced and the amplitude of the "echo" gains swiftly, i.e. the form of the sending is strongly modified. Distortions depending on the nonuniformity of the frequency characteristic are more feebly expressed. With the change K_1 the amplitude of the fundamental pulse does not change at all, only the "echo" amplitudes are changed, i.e. a certain "spreading out" of the signal in time occurs. We will consider the distortions allowable (Fig.5) if $I_0(\tau'_0) \cong 1$ (and this will be with

$+\tau'_0 \leqslant 1$), and if the condition is fulfilled: $\frac{K_1}{2} I_0(\tau'_0) + K_0 I_1(\tau'_0) \leqslant \frac{U_{min}}{2}$, in which U_{min} is the threshold voltage in the minimum. In particular with $\tau'_0 \approx 0$, both conditions amount to one: $K_1 \leqslant U_{min}$. It is important to note that the conditinns derived do not depend on m, i.e. on the number of filters.

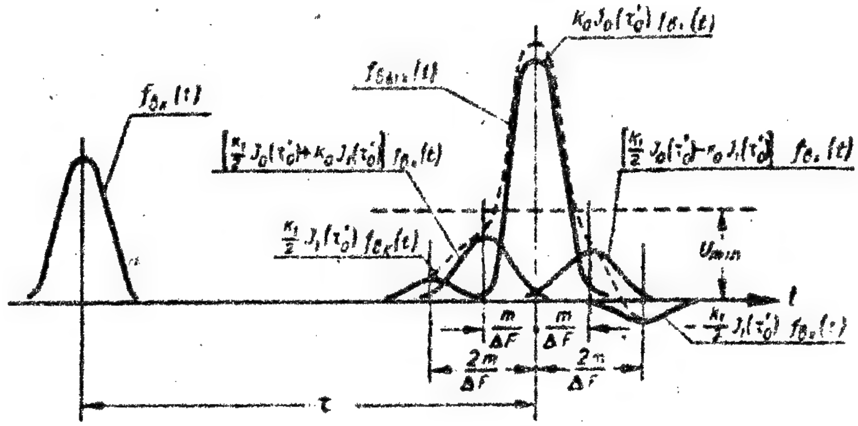

Fig.5. Frequency and Phase Distortions of Elementary Telegraphic Sending.

Findings of Experiments

Inasmuch as the purpose of the research was to ascertain in principle the possibility of employing the phase preselection method in systems of telegraphic communications, the experiments were conducted on an apparatus whose parameters were designed and changed in the testing process in accordance with previously derived theoretical data. The transmitter's stretching device and the receiver's compensating device were made according

the Fig. 1 circuit. In each of both devices the delays of the signal in time were achieved by means of a magnetic sound recorder, in which instead of one head, seven magnetic playback heads reproducing signals, arranged in an appropriate manner, were installed. Each head was connected up to its frequency filter. From the output of filters the signal entered a summation device, from where it was supplied to the transmitter's modulator (in the case of a stretching device) or to the terminal instrument (in case of a compensating device). In the experimental unit, the possibility was provided for connecting an amplitude limiter before the compensating device.

The oscillograms obtained as a result of experiments on the apparatus indicated above, are shown in Fig.6. At the receiver input in the time segment t_1 only a useful signal entered, in the time segment t_2 - a useful signal with pulse noises that were not subject to limitation in the receiving device, and finally, in the time segment t_3 a useful signal was received with pulse noises with amplitude limiter connected. Each elementary sending was stretched approximately 70 times in the system.

As is evident from the oscillograms, the compensation of the useful signal's phase preselections was quite satisfactory. Moreover, with use of the method of phase

preselections, the communication system's noiseproof feature was enhanced appreciably. The result of stretching in time the pulse noises in the compensating device is seen in the oscillograms of Fig.6,c. In consequence of stretching the noise pulses vanished, and in place of them a peculiar "ripple" appeared in the useful signal. With use of the amplitude limiter the communication system's noiseproof feature was raised still more, since the "ripple" almost disappeared.

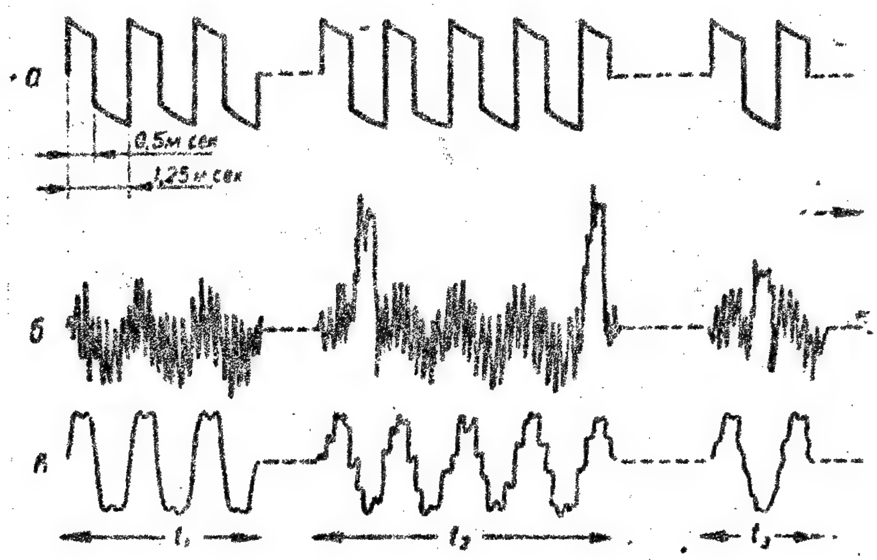

Fig.6. Oscillograms: a - input signal; b - signal at the output of the receiver's detector; c - signal at output of receiver.

Conclusion

The foregoing permits drawing the conclusion that the method of phase preselections with simultaneous

limitation of strong pulse noises in the receiving device represents a method of accomplishing in practice the idea of group transmission of elementary signals. With suitable development of the transmitting and receiving sets, the given method can secure a gain in the noiseproof feature of radiotelegraphy in the operating conditions of strong pulse noises.

Preliminary experimental findings on the system's noiseproof feature were given above. Detailed examination of the noiseproof feature problem is outside the framework of this study and merits special consideration.

The author expresses profound gratitude to Prof. D.V.Ageyev for a number of valuable suggestions he made when this study was in progress.

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Problem of Transient Conditions in Logarithmic Video Amplifiers

8

by V.M.Volkov

Typical characteristics of transient conditions in video amplifiers with logarithmic amplitude characteristic are examined. The dependence of the pulse set up time at the amplifier output, of the value of the pulse's flat top droop and the parasitic back overshooting on the input signal level is given. Possible ways of reducing parasitic overshooting are indicated.

Logarithmic amplitude characteristic (LAC) can be obtained in a video amplifier through employment of nonlinear elements. In view of the nonlinear elements present the transient conditions in logarithmic video amplifiers have a number of characteristics, chief of which are:

(1) drastic reduction in pulse set up time with rise of input voltage;

(2) drastic increase of parasitic back overshooting with rise of input voltage. The appearance of substantial

overshooting makes impossible practical use of logarithmic video amplifiers with dynamic range above 50 to 55 db.

Below transient conditions are examined in a video amplifier in which LAC is obtained through shunting the anode loads of the amplifying cascades with nonlinear elements; recommendations are given on reduction of parasitic back overshooting.

The equivalent circuit of a nonlinear cascade is shown in Fig.1, in which g_a is the conductance of anode resistance; g_{nonl} is the conductance of the nonlinear element; g_c is the resistance leakage conductance; g_1 is the output conductance of the given cascade tube; g_{in} is the input conductance of the following cascade tube; C_o is the parasitic capacitance shunting the anode load of the cascade; C_c is the transient capacitance.

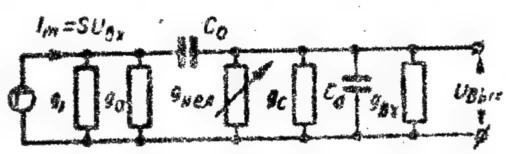

Fig. 1.

Either vacuum diodes or germanium diodes of the DG-Ts, D2 and D9 types can be used in the capacity of nonlinear elements.

In a single nonlinear cascade it is very difficult to obtain LAC in a range above 15 to 20 db. It can, however,

be obtained in a very wide range by means of several non-linear cascades which with rise of input voltage operate alternately in logarithmic conditions (alternate operation of nonlinear cascades). Shown in Fig.2 are the amplitude characteristics of a nonlinear cascade requiring n cascades to secure alternate operation, N = 2.72 (curve 1) and N = 10 (curve 2) for the two values of the basis of taking logarithms. In Fig. 2 the numeral I designates the linear section of the amplitude characteristic from 0 to input voltage U_{in1}, numeral II the logarithmic section from U_{in1} to U_{in2} and numeral III the quasilinear section. In future we will provisionally designate with appropriate index all variable magnitudes referring to the given sections of the amplitude characteristic.

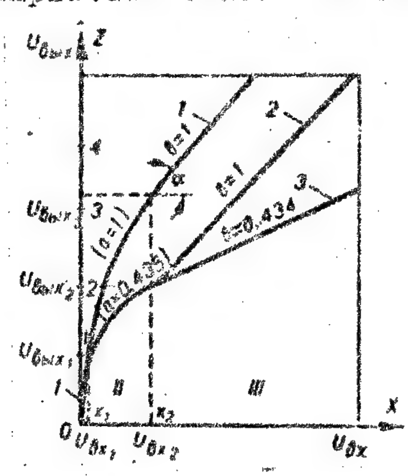

Fig. 2

For community of analysis of the transient conditions we introduce the relative values of the input x and the

output z voltages: $x = \frac{U_{in}}{U_{in1}}$; $z = \frac{U_{out}}{U_{out1}} = \frac{U_{out}}{K_1 U_{in1}}$,

in which U_{in} and U_{out} are respectively the current input and output voltages of the nonlinear cascade; U_{in1} and U_{out1} are the input and output voltages, at which the LAC of the cascade begins; K_1 is the maximal amplification factor of the nonlinear cascade.

Each section of the nonlinear cascade's amplitude characteristic can be expressed analytically as follows:

(a) the linear section (with $z \leqslant 1$) $z = x$;

(b) the logarithmic section (with $1 \leqslant z \leqslant a \ln D_1 + 1$) $z = a \ln x + 1$;

(c) the quasilinear section (with $z \geqslant a \ln D_1 + 1$)

$$z = a \ln D_1 + (1 - b) + \frac{bx}{D_1},$$

in which $D_1 = \frac{U_{in2}}{U_{in1}} = \frac{x_2}{x_1}$ is the range of LAC of the nonlinear cascade;

$\delta = \frac{\Delta U_{outIII}}{\Delta U_{inIII}}$ is the differential amplification factor in the quasilinear section of the cascade characteristic, numerically equal to the ratio of the output voltage increase to the input voltage increase;

$a = 1/\ln N$ is a coefficient characterizing the LAC slope with different bases of taking logarithms N.

To secure alternate operation of n nonlinear

cascades with different coefficients a not equal to unity it is essential in the last nonlinear cascade to fulfill the condition $K_1 = D_1$ and $a = b \neq 1$ (curve 3 in Fig.2) and to secure fulfillment of the condition $K_1 = D_1$ and $a = b = 1$ (Curve I in Fig.2) in all the remaining nonlinear cascades preceding the last cascade.

Inasmuch as distortions of the pulse front depend on the frequency characteristic of the nonlinear cascade in the zone of high frequencies, and the distortions of the pulse flat top depend on the frequency characteristic in the zone of low frequencies, it is expedient to separate from the general equivalent circuit of the cascade the equivalent circuits for the high and low frequencies and to examine the transient conditions separately in each of these circuits.

The equivalent circuit of the nonlinear cascade for the range of high frequencies is pictured in Fig.3 in which $\varepsilon_{enonl} = \varepsilon_o + \varepsilon_{nonl}$.

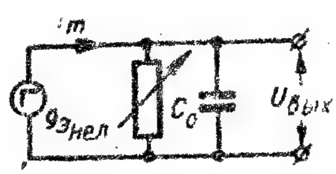

Fig.3.

With the action of voltage jump U_{in} at the input of the nonlinear cascade at the time moment $t = 0$, the

transient conditions in the circuit of Fig.3 are described by the following nonlinear differential equation:

$$\frac{dU_{out}}{dt} + \frac{g_{enonl}}{C_o} U_{out} = \frac{SU_{in}}{C_o}.$$

To obtain the amplitude characteristic of a nonlinear cascade, essential for securing alternate operation of cascades, the conductance g_{enonl} must be varied according to the law $g_{enonl} = g_o \varphi(z)$ where the function $\varphi(z)$ is determined by the expression:

$$\varphi(z)=\begin{cases} 1 & \text{for } z\leqslant 1 \\ \dfrac{e^{\frac{z-1}{a}}}{z} & ,\ 1\leqslant z\leqslant a\ln D_1+1 \\ \dfrac{D_1}{b\cdot z}(z-a\ln D_1-1+b) & ,\ z\geqslant a\ln D_1+1 \end{cases} \quad (1)$$

a- with

At the same time

$$g_0 = g_i + g_a + g_{ex} + g_c .$$

After the substitution in (1) of conductance g_{enonl}, relative time $\alpha = t/C_oR_o$ and relative voltages x and z, we have

$$\frac{dz}{d\alpha}+\varphi(z)z = x(\alpha). \quad (2)$$

In equation (2) the variables are readily isolated

$$\alpha = \int \frac{dz}{x(\alpha)-\varphi(z)z} + C. \quad (3)$$

The solution of integral (3) with consideration of initial conditions for various sections of the amplitude characteristic of the cascade has the form:

(a) for the linear section ($z \leqslant 1$)

$$\alpha_{I} = \ln \frac{x}{x-z};$$

(b) for the logarithmic section $(1 \leqslant z \leqslant a \ln D_1 + 1)$ (4)

$$\alpha_{II} = \frac{z-1}{x} + \ln \frac{x}{x-1} + \frac{a}{x} \ln \frac{x-1}{x - e^{\frac{z-1}{a}}}; \tag{5}$$

(c) for the quasilinear section

$$\alpha_{III} = \ln \frac{x}{x-1} + \frac{a}{x} \ln \frac{D_1(x-1)}{x-D_1} + \frac{b}{D_1} \ln \frac{\frac{x}{D_1} - 1}{\frac{x}{D_1} + \frac{a \ln D_1 + 1 - b}{b} - \frac{z}{b}}. \tag{6}$$

The transient characteristics of the nonlinear cascade during operation in logarithmic and quasilinear conditions $\Theta = \frac{U_{out}}{U_{outm}} = f(\alpha)$ for the case $a = b = 1$, calculated according to formulas (4), (5), (6), are pictured in Fig.4. In calculation of the characteristic, the most probable LAC range of cascade, $D_1 = 10$ is taken. The transient characteristics for the quasilinear cascade operating conditions are calculated for $x = 10, 33, 56, 79$ and 102, which correspond to the relative voltages at 1, 2, 3, 4 and 5 inputs of nonlinear cascades in the end of the logarithmic

range of a five-cascade amplifier. It is evident from Fig.4 that with the rise of the input signal, the pulse set up time t_s and delay time t_d at the output of the nonlinear cascade are drastically reduced. Under set up time is implied the time of pulse growth from 0.1 to 0.9 of its maximal value. The delay time corresponds to the time of pulse growth from 0 to 0.5 of its maximal value. Shown in Fig.5 are graphs of the relative changes of the set up time $\eta(x) = \frac{t_y}{t_{y\,x<1}}$ and delay time $\chi(x) = \frac{t_3}{t_{3\,x<1}}$ for a = b = 1 and a = b = 0.435. Fig.5 shows that the maximal rate of change of t_s and t_d is observed with variation of the input voltage in the range equal to the LAC range of the cascade ($1 \leqslant x \leqslant D_1$). With reduction of factor a, which corresponds to an increase of the basis of taking logarithm N, the relative variation t_s and t_d increase.

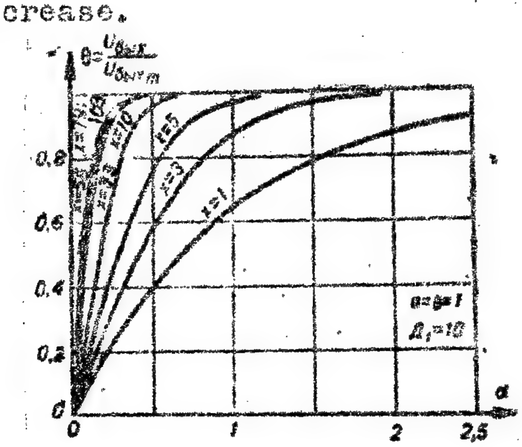

Fig.4

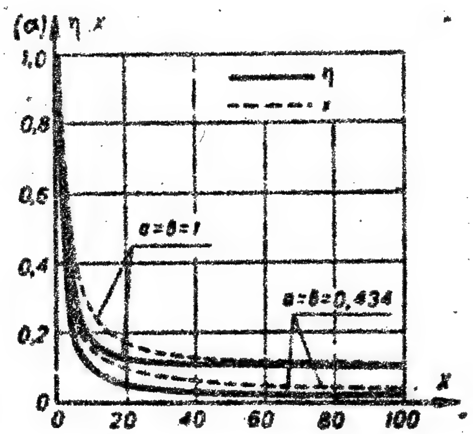

Fig.5

The equivalent circuit of a nonlinear cascade for lowest frequencies is shown in Fig.6. Estimates made by the author and experimental investigations showed that with $R_a \geqslant 1$ kohm, $C_c = 0.1$ to 0.05 microfarads and the durations of pulses $t_p = 5$ to 10 microseconds; the current flowing in the circuit and the resistance R_{nonl} of the nonlinear element remain practically constant during the pulse action time. The Fig.6 circuit can, therefore, be considered linear with a sufficient degree of accuracy during the pulse action. It must at the same time be taken into account that to each value x corresponds its own R_{nonl} value. The most interesting value characterizing transient conditions during pulse action is the relative droop of the pulse flat top Δ, numerically equal to the ratio of the absolute flat top droop at the end of pulse action to the maximum value of the pulse. Inasmuch as the cascade is linear, the relative droop Δ at the nonlinear cascade output determined by capacitance C_c charge, will, at the end of pulse action, be equal to

$$\Delta = \frac{t_u}{C_c\,(R_{нел} + R_a)}. \qquad (7)$$

The expression (7) is correct in case of fulfillment of inequation $C_c(R_a + R_{nonl}) \gg t_u$ which is practically always fulfilled. After substitution in equation (7) of

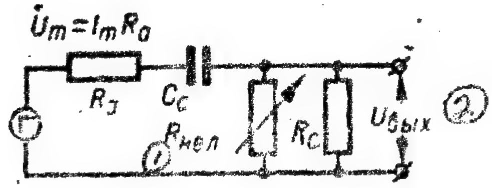

Fig.6

1- R_{nonl}

2- U_{out}

resistance $R_{nonl} = \frac{1}{q_{nonl}}$, found from (1) and expressed through x, for the various sections of the nonlinear cascade amplitude characteristic, we derive:

(a) for the linear section ($0 \leqslant x \leqslant 1$)

$$\Delta_I = \frac{t_u}{C_c(R_a + R_c)};$$

(b) for the logarithmic section ($1 \leqslant x \leqslant D_1$)

$$\Delta_{II} = \frac{t_u(x - a\ln x - 1)}{C_c R_a x};$$

(c) for the quasilinear section ($x > D_1$)

$$\Delta_{III} = \frac{t_u\left(x - a\ln D_1 - 1 - b\frac{x}{D_1} + b\right)}{C_c R_a x}.$$

After pulse action ceases capacitance C_0 is discharged through two resistances R_a and R_{nonl} connected in parallel. Owing to the increase of resistance R_{nonl} in the process of capacitance C_0 discharge, the pulse droop will be somewhat stretched and the pulse droop time with $x \geqslant D_1$

will, as experimental and theoretical research has shown, be two to three times greater than the set up time. The transient conditions during capacitance C_o discharge are described by equation (2).

Worthy of attention is the formation of a parasitic back overshooting with capacitance C_c discharge after pulse action stops. The equivalent circuit of capacitance C_c discharge is pictured in Fig.7. R'_{nonl} designates the resistance of the nonlinear element in which is isolated the voltage of parasitic overshooting U_o. It is readily shown that the relative overshooting, equal to the ratio of overshooting voltage to the maximal pulse value U_{out_m} at the nonlinear cascade output is equal to

$$d = \frac{U_o}{U_{\text{вых} m}} = -\frac{t_u}{C_c(R_a + R'_{\text{нел}})} \cdot \frac{R'_{\text{нел}}}{R_{\text{нел} c}}$$

With fulfillment of inequation $U_o \leqslant U_{out_1}$ (this inequation is practically always fulfilled in case $1 \leqslant x \leqslant 10^2$) $R'_{nonl} = R_c \gg R_a$ occurs.

Then

$$d = \frac{t_u}{R_{\text{нел}} C_c}. \qquad (8)$$

After substitution in (8) of the expression for R_{nonl}, we derive respectively for the linear, logarithmic and quasilinear sections of the cascade amplitude charact-eristic:

$$d_I = \frac{t_u}{C_c(R_a + R_c)}; \qquad d_{II} = \frac{t_u(x - a\ln x - 1)}{C_c R_a (a\ln x + 1)};$$

$$d_{III} = \frac{t_u\left(x - a\ln D_1 - 1 - b\frac{x}{D_1} + b\right)}{C_c R_a\left(a\ln D_1 + 1 + b\frac{x}{D_1} - b\right)}.$$

For community it is expedient to introduce the new values β and γ, characterizing the variation Δ and d, but independent of the nonlinear cascade elements C_c and R_a and pulse duration t_u:

$$\beta = \Delta\frac{C_c R_a}{t_u}; \qquad \gamma = d\frac{C_c R_a}{t_u}.$$

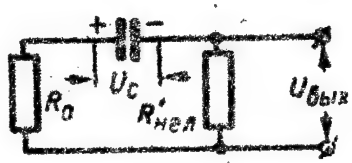

Fig.7

Shown in Fig.8 are the dependencies $\beta(x)$ and $\gamma(x)$ for the cases $a = b = 1$ and $a = b = 0.434$ with the correlation $\frac{R_a}{R_c} = 0.02$. By this curve it can be found that for the more real case(R_a = 2 kohm; C_c = 0.1 microfarad; $D_1 = 10$; t_p = 1 microsecond) in the nonlinear cascade (with $x = 102$) as compared with the linear cascade, the relative pulse droop can exceed ten-fold and the relative overshooting a hundred fold. Such a drastic rise of parasitic back overshootings in separate nonlinear cascades

leads naturally to a drastic rise of the back overshooting at the output of the n-cascade logarithmic video amplifier.

The differential equation which describes the transient conditions at the output of the i nonlinear cascade of the n-cascade amplifier at the initial moment of pulse action can be written as follows:

$$\frac{dz_i}{d\alpha} + \varphi(z) z_i = K_1 z_{i-1}(\alpha), \qquad (9)$$

in which $z_{i-1}(\alpha)$ is the relative voltage at the output of (i — 1) nonlinear cascade.

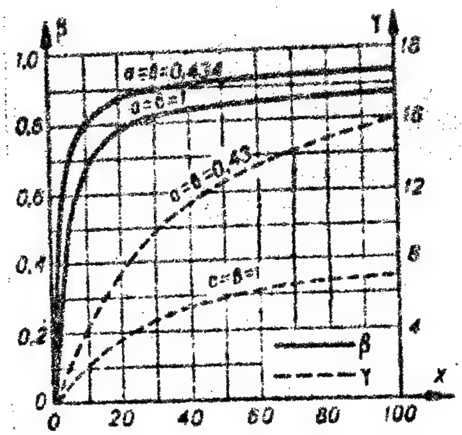

Fig.8

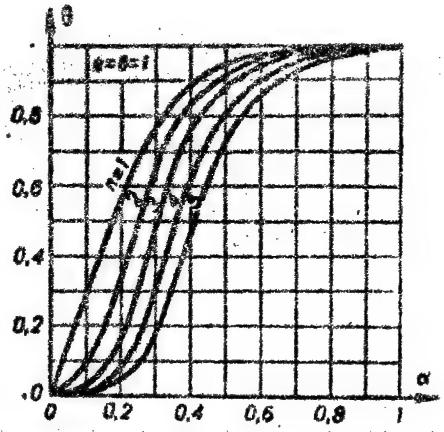

Fig.9

The transient characteristics for a different number of nonlinear cascades with a = b = 1 and D_1 = 10 are shown in Fig.9. The characteristics are plotted by means of a graphoanalytical solution of equation (9) [2]. With any n the solution is developed for the end of the logarithmic range of an n-cascade amplifier, which corresponds to the

relative voltage at the input of the first cascade $x = D_1$. Through the comparison of the transient characteristics pictured in Fig.9 with the n-cascade linear amplifier characteristics, Table 1 is drawn up showing the relative variation t_s and t_d of the amplifier with input voltage corresponding to the end of the logarithmic range as compared with the $t_{s\,lin}$ and $t_{d\,lin}$ when the amplifier amplifies small signals and operates in linear conditions.

Table 1

n	1	2	3	4	5
$\xi = \dfrac{t_{s\,log}}{t_{s\,lin}}$	0.177	0.119	0.097	0.084	0.0835
$\delta = \dfrac{t_{d\,log}}{t_{d\,lin}}$	0.24	0.154	0.117	0.098	0.09

Table 1 shows that with $n \geqslant 5$ the values ξ and δ remain practically constant.

The relative droop of the pulse flat top at the output of the n-cascade logarithmic video amplifier is equal to

$$\Delta_0 = \sum_{i=1}^{i=n} \Delta_{i\,\cancel{max}\,out} \qquad (10)$$

in which $\Delta_{i\,out}$ is the component of the general relative

droop determined by the droop formed in the i cascade.

The expressions for $\Delta_{i\ out}$ will differ with the operation of nonlinear cascades in differing conditions. It is readily shown that with the operation of nonlinear cascades:

(a) in linear conditions

$$\Delta_{i\,вых} = \frac{a \ln \frac{1}{1-\Delta_1}}{a \ln X + 1}; \qquad (11)$$

(b) in logarithmic conditions

$$\Delta_{i\,вых} = \frac{\left(a \ln \frac{X}{D_1^{n-i}} + 1\right)\Delta_{II}}{a \ln X + 1}; \qquad (12)$$

(c) in quasilinear conditions

$$\Delta_{i\,вых} = \frac{\left(a \ln \frac{X}{D_1^{n-i}} + 1\right)\Delta_{III}}{a \ln X + 1}; \qquad (13)$$

in which $X = U_{in}/U_{in\ h}$ is the relative voltage at the input of the n-cascade video amplifier; $U_{in\ h}$ is the input voltage at which the LAC of the video amplifier begins; n - is the number of nonlinear cascades.

In the n-cascade video amplifier for the i nonlinear cascade the expression (11) is correct in case $1 \leqslant X \leqslant D_1^{n-i}$; the expression (12) in case $D_1^{n-i} \leqslant X \leqslant D_1^{n-i+1}$, the expression (13) in case $D_1^{n-i} \leqslant X \leqslant D_1^{n}$.

If in the expressions (11) to (13) instead of Δ_I, Δ_{II} and Δ_{III} we substitute β_I, β_{II} and β_{III}, we

derive the new values $\beta_{i\ out} = \Delta_{i\ out} \frac{C_c R_a}{t_p}$ that do not depend on the elements C_c and R_a of the nonlinear cascades and pulse duration t_u. At the same time for the n-cascade video amplifier is fulfilled the equation

$$\beta_0 = \sum_{i=1}^{i=n} \beta_{i\,out}.$$

Shown in Fig.10 are the dependencies $\beta_0(X)$ for the five-cascade logarithmic video amplifier for $a = 1$ and $a = 0.434$. The most probable case $D_1 = K_1 = 10$ is taken in calculating the dependencies $\beta_0(X)$. The curves of Fig.10 make it

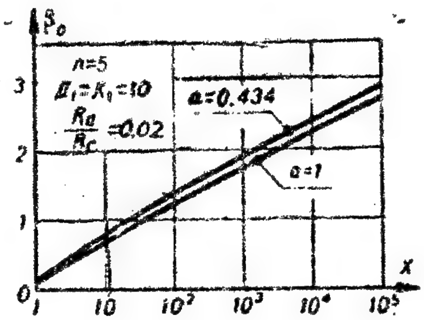

Fig. 10

possible to determine the relative droop of the pulse flat top at the output of the five-cascade amplifier, taking logarithms according to the law of the natural and the decimal logarithm in the range D = 100 db, with any values of R_a, C_c, t_p and $\frac{R_a}{R_c} = 0.02$. So, for example, for the end of the logarithmic range of the amplifier ($X = 10^5$) with $a = 1$, R_a = 2 kohm; C_c = 0.1 microfarad and t_u = 1 microsecond), we derive Δ_0 = 2.7 %, which

is 54 times greater than the relative droop of the linear five-cascade amplifier with the same values of R_a, C_c, R_c and t_u.

In the case of an ideal pulse's action, without back overshooting, at the input of an n-cascade logarithmic video amplifier, the relative overshooting at the output of the video amplifier will be equal to

$$d_0 = \sum_{i=1}^{i=n} d_{i\,out}. \qquad (14)$$

in which $d_{i\ out}$ is the component of the general relative overshooting determined by the overshooting formed in the i nonlinear cascade.

It is essential to note that formulas (10) and (14) are correct in case $\Delta_{i\ out} \leqslant (10 \text{ to } 15)$ % and $d_{i\ out} \leqslant (10 \text{ to } 15)$ %.

The parasitic back overshootings that are formed in nonlinear cascades are substantially less than the signal. Consequently, whereas the signal is amplified according to the logarithmic law, the back overshootings are amplified according to linear law. Conformity to this principle determines the drastic rise of the added sums (14) with signal rise at the amplifier input. Calculations and experiment have shown that in case t = 1 microsecond, R_a = 2 kohm and C_c = 0.1 microfarad, the relative overshooting is

increased to 60 % by the end of the logarithmic range of 70 db (with a = 1) at the output of the video amplifier consisting of nonlinear cascades, the equivalent circuit of which is pictured in Fig.1.

The characteristic of the logarithmic video amplifier to emphasize back overshootings is manifested also in the case when parasitic back overshootings are not formed in the video amplifier itself (the ideal video amplifier), and real pulses with negligible back overshooting enter its input.

Calculations and experiment show that in case of taking logarithms according to the natural logarithm law, the relative overshooting at the output of the ideal video amplifier at the end of the 70 db logarithmic range is equal to $d_o = 10\ \%$ when the relative overshooting at the input is $d_{in} = 0.01\ \%$, that $d_o = 32\ \%$ in case $d_{in} = 0.1\%$ and $d_o = 54\ \%$ in case $d_{in} = 1\ \%$. With increase of the basis of taking logarithms (reduction of a) the value d_o increases.

In this way with growth of input voltage, the pulse set up time at the output of an n-cascade logarithmic video amplifier consisting of amplifying cascades with nonlinear elements in the anode circuit, is drastically reduced while the droop of the pulse flat top and parasitic back overshooting

drastically increase.

If the logarithmic video amplifier is preceded by a linear amplification channel, then for reduction of the pulse flat top droop and the parasitic overshooting at the output of the logarithmic video amplifier, it is necessary to adopt measures for reduction of the droop and back overshooting of the video amplifier's nonlinear cascades as well as in the channel connected ahead of the logarithmic video amplifier.

If the nonlinear element shunting the anode load of the cascade is connected before the intermediate capacitance C_c, the droop of the pulse flat top and parasitic back overshooting are reduced considerably. In the given case with fulfillment of the inequation $R_c \gg R_a$ the values Δ_{nonl} and d_{nonl} for the nonlinear cascade are equal to the values Δ_{lin} and d_{lin} for the linear cascade. All the formulas derived earlier for the n-cascade logarithmic video amplifier are correct also with connection of nonlinear elements before the intermediate capacitance.

It is thus essential in designing n-cascade logarithmic video amplifiers that nonlinear elements be connected before intermediate capacitances.

All the theoretical theses expounded in the article have been verified by experiment.

The author expresses profound gratitude to Prof. N.F.Vollerner for valuable suggestions in this study.

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Glossary of Russian symbols used:

$U_{в}$ Uovershooting
$U_{вх}$ U input
$U_{вых}$ U output
$R_{нел}$ R nonlinear
$U_{вхн}$ U input begins

$t_{у}$ t set up time
$t_{з}$ t delay time
$t_{и}$ t pulse duration , also uses tu

CSO:4341-N/RT5

Brief Reports

On the Theory of the Frequency Characteristics of Photoresistors and Luminophors.

9

by V.A.Malyshev

In a number of physical and technical devices, the conversion takes place of light pulses into current pulses by means of photoresistors or the conversion of a luminophor's radiation pulses into light pulses of luminescence. The dependence of the amplitude of output signals on the frequency of the primary is called the frequency characteristic. This characteristic can be determined by the properties of the substance exposed to radiation as well as by the intensity of the pulses of primary radiation. Set forth below is the theory of the dependence of the frequency characteristic trend of photoconductance and luminescence on the character of the electronic processes that take place in a photoresistor or luminophor.

Let us examine the two simplest laws of recombination -- the linear and the quadratic. For the case of the quadratic law of recombination, a kinetic equation for

concentration of n carriers of current can be reached:

$$\frac{dn}{dt} = N - \alpha n^2 \;, \qquad (1)$$

in which N is the number of current carriers formed every second per unit of volume on account of primary radiation; α is the probability of recombination of a current carrier with one of the recombination centers per unit of time.

In case of irradiation with square form pulses the value N is constant in time. With the initial condition $t = 0$, $n = n_0$ the solution of equation (1) has the form:

$$n = \sqrt{\frac{N}{\alpha}} \; \frac{\operatorname{th}\left[\sqrt{N\alpha}\; t\right] + \sqrt{\frac{\alpha}{N}}\; n_0}{1 + n_0 \sqrt{\frac{\alpha}{N}}\; \operatorname{th}\left[\sqrt{N\alpha}\; t\right]} \qquad (2)$$

and characterizes the law of the growth of photoconductance in time. If the recombination of current carriers is accompanied by luminescence, then the value αn^2 gives the law of luminescence variation.

To determine the law of the droop of photoconductance and luminescence after termination of the radiation pulse, the equation (1) should be solved, after having put $N = 0$ in it with initial conditions $t = 0$, $n = n_1$. This solution has the form:

$$n = \frac{n_1}{1 + a n_1 t} \qquad (3)$$

But if it is assumed that the recombination follows the linear law, then the kinetic equation assumes the form:

$$\frac{dn}{dt} = N - \beta n , \qquad (4)$$

in which β is the probability of the recombination of a single current carrier in a unit of time. If the recombination is accompanied by luminescence, then βn shows the number of acts of luminescence per unit of time. The solution of equation (4) gives the law of the growth of photoconductance in the form:

$$n = \frac{N}{\beta}\left(1 - e^{-\beta t} \right) + n_0 e^{-\beta t} \qquad (5)$$

and the law of droop in the form:

$$n = n_1 e^{-\beta t} . \qquad (6)$$

It is evident that in this case the variations of photocunductivity and luminescence in time are subject to an identical conformity to principle.

Assuming that the irradiatian is conducted continuously with arriving pulses of square form with fill factor γ and period T, then from (2) and (3) we derive:

$$n_1 = \sqrt{\frac{N}{\alpha}} \cdot \frac{\operatorname{th}[\gamma T \sqrt{N\alpha}] + n_0 \sqrt{\frac{\alpha}{N}}}{1 + n_0 \sqrt{\frac{\alpha}{N}} \operatorname{th}[\gamma T \sqrt{N\alpha}]}; \tag{7}$$

$$n_0 = \frac{n_1}{1 + \alpha n_1 T(1-\gamma)} . \tag{8}$$

From (7) and (8) can be determined the magnitude $A = n_1 - n_0$, proportional to the amplitude of photoelectric current pulses

$$A = \sqrt{\frac{N}{\alpha}} \; \frac{T(1-\gamma)\sqrt{N\alpha}\, \operatorname{th}[\gamma T \sqrt{N\alpha}]}{T(1-\gamma)\sqrt{N\alpha} + \operatorname{th}[\gamma T \sqrt{N\alpha}]} . \tag{9}$$

For the second recombination mechanism being examined, from expressions (5) and (6) can be derived

$$A = \frac{N}{\beta} \; \frac{\left(1 - e^{-\beta(1-\gamma)T}\right)\left(1 - e^{-\beta\gamma T}\right)}{1 - e^{-\beta T}} . \tag{10}$$

From the expressions (7) and (8), the correlation can be derived that determines the amplitude of luminescence pulses in case of the first (quadratic) recombination mechanism

$$\Phi = \alpha(n_1^2 - n_0^2) =$$
$$= B\frac{\sqrt{\operatorname{th}(\gamma T\sqrt{N\alpha})\,[4 + \alpha N(1-\gamma)^2 T^2] + 4(1-\gamma)T\sqrt{N\alpha}}}{[(1-\gamma)T\sqrt{N\alpha} + \operatorname{th}(\gamma T\sqrt{N\alpha})]^2} . \tag{11}$$

where $B = N\sqrt{N\alpha}\,(1-\gamma)T\operatorname{th}^{1/2}[\gamma T\sqrt{N\alpha}]$.

In case of the second mechanism $\Phi = \beta A$, where A is determined by expression (10).

In the majority of cases $\gamma = \frac{1}{2}$. Then the expression (9) assumes the form:

$$A = \sqrt{\frac{N}{\alpha}} \cdot \frac{\operatorname{th}\left(\frac{1}{x}\right)}{1 + x\operatorname{th}\left(\frac{1}{x}\right)} . \qquad (12)$$

in which $x = \frac{2}{T\sqrt{N\alpha}}$, a magnitude proportional to the frequency of the radiation signals.

Besides (10) can be written in the form:

$$A = \frac{N}{\beta} \cdot \frac{1 - e^{-1/y}}{1 + e^{-1/y}} . \qquad (13)$$

in which $y = \frac{2}{\beta T}$, and the expression (11) assumes the form:

$$\Phi = N \frac{\operatorname{th}^{3/2}\left(\frac{1}{x}\right)\sqrt{(1 + 4x^2)\operatorname{th}\left(\frac{1}{x}\right) + 4x}}{\left|1 + x\operatorname{th}\left(\frac{1}{x}\right)\right|^2} . \qquad (14)$$

The dependencies (12),(13) and (14)characterize the frequency characteristics of photoconductance and luminescence. Represented in Fig.1 are graphs of the dependencies of the relative amplitudes of output pulses ($A\sqrt{\alpha/N}$; $A\beta/N$; Φ/N) on values proportional to the frequency of the primary radiation (x or y). These graphs are in essence the generalized frequency characteristics of the photoresistors and luminophors.

From correlation (13), it follows that with variation of radiation intensity (proportional for linear light

characteristic value N), the relative frequency character=istic does not change its form in case of the second recombination mechanism. Since at the same time photoconductance and luminescence have identical time run and identical generalized frequency characteristics, the property mentioned relates to both phenomena.

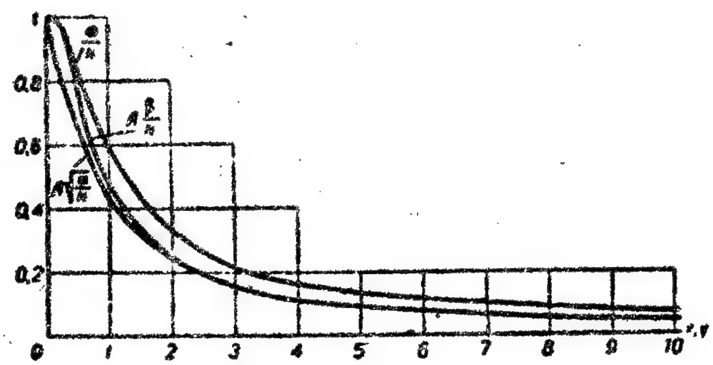

Fig 1

In the case of the first recombination mechanism, as follows from expressions (12) and (14), the steep slope of the relative frequency characteristic of photoconductance and luminescence is reduced with growth of radiation intensity, whereupon the increase of intensity corresponds k times to the same increase of relative amplitude, as an $\sqrt{k}$ times frequency reduction.

The mentioned properties of the frequency characteristics can be put at the basis of an experimental method of determining the recombination mechanism active in the substance.

From correlations (12),(13) and (14) it follows that at high frequencies the generalized frequency characteristics of photoresistors and luminophors for both mechanisms of recombination are identical and subjected to the law of inverse proportionality.

Fig. 1 makes it possible to judge roughly about the mechanism of the recombinations occurring in the substance from the form of the frequency characteristic of photoresistors. A law of luminous flux modulation differing from rectangular modulation can be used in taking the frequency characteristic. There is no doubt that the singularities of the frequency characteristics that distinguish one law of recombination from another, are in some degree preserved also with other types of modulation. The frequency characteristics of industrial models of photoresistors [1], which were taken under the luminous flux modulation law, distinguished from the square law, in our opinion, therefore, show that monopolar recombination occurs (at 20° C) in lead sulfite photoresistors (FS-A1) and bipolar recombination occurs in cadmium sulfite photoresistors (FS-K1).

It should be noted that with the mechanisms of recombination examined, the frequency characteristics derived in this study are correct in the first approximation both for the conductivity excited in the substance by the

pulses of electrons bombarding the substance (cathode conductance) as well as for the cathode luminescence. The applicability of the derived correlations in these cases is the more accurate, the less the intensity of primary radiation is and the greater the energy of the electrons bombarding the substance.

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Brief Reports

Problem of Similarity of Devices Based on the Faraday and Hall Effects

10

by Ye.T.Skorik

Devices employing ferrites have recently found wide application in the range of super high frequencies. Of greatest practical and theoretical interest at the same time is the use of the irreversible properties of ferrites at super high frequencies, since a passive waveguide medium that does not satisfy the reciprocity principle has not been met previously in communication engineering. Along with the irreversible properties, the reversible properties of ferrites are also used for the creation of new types of modulators, attenuators and phase inverters regulated by magnetic field.

Frequently utilized in ferrite devices of the super high frequency range is the Faraday effect which in this case is manifested in turning of the electromagnetic wave's plane of polarization during its passage through a longitudinally magnetized ferrite. The low frequency limit of the application of such devices is, therefore, limited by the frequencies at which the waveguide methods of transmitting

electromagnetic energy can still be applied.

The new semiconductor materials with high carrier mobility, recently proposed, open up the possibility for wide technical application of galvanomagnetic effects in semiconductors, the Hall effect in particular. The Hall effect consists in the appearance of an alternate difference of potentials in the specimen with current because of the deviation of charge carriers when the specimen is placed perpendicular to the magnetic field current. On the basis of the Hall effect, devices can be designed that operate in a wide range of frequencies (from low to super high frequencies), devices which in purpose and their properties very much resemble devices of the super high frequency range using the Faraday effect. Of interest is a generalization of the data available in the literature from the viewpoint of drawing an analogy between the groups of devices based on the Faraday and Hall effects.

The basis of all devices violating the reciprocity principle is the gyrator-linear quadripole, in which with the passage of a signal in one direction, a phase shift is formed different by π from the phase shift in the other direction[1]. The gyrator based on the Faraday effect has been described in many works, in [1] in particular. Shown in Fig. 1a is a sketch of a gyrator using the Faraday

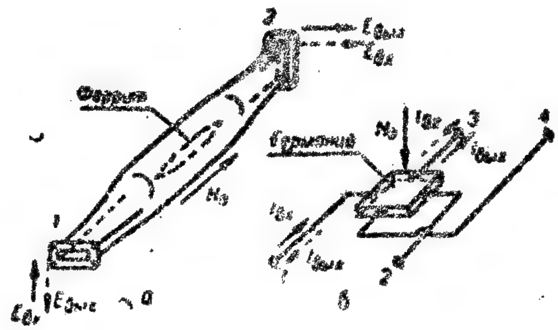

Fig.1

a - ferrite
b - germanium
c - output
d - input

effect. With passage of the signal from channel 1 in the presence of a longitudinal magnetic field sufficient for slewing by 90° the polarization plane, the signal from channel 2 emerges with the orientation of vector E indicated in the drawing. With back passage of the signal from 2 to 1, the orientation of vector E at the output is changed in reverse, which is equivalent to a phase shift by π.

It has been demonstrated in [2] that the Hall e.m.f. pickup unit is also a gyrator (Fig.1,b). Actually, with current at the 1 - 2 input circuit of the direction indicated in the drawing, the direction of the current appearing in the 3 - 4 output circuit is, owing to the Hall effect, determined according to the known "left hand" rule; with passage of current of the same direction in the 3 - 4

circuit, the current in 1 - 2 circuit changes its direction to the opposite. Such a gyrator is sufficiently wideband, since its irreversible properties are violated only in the frequencies at which the capacitance current becomes comparable with the conductance current, which for germanium corresponds to a frequency of about 10^{10} cycles per second.

On the basis of the gyrator it is quite simple to design a device called an insulator or valve [1,3].

The sketch of a waveguide design insulator on the basis of the Faraday effect is shown in Fig.2a. Characteristic in such a construction is the turning by 45° of the polarization plane of the wave passing through the ferrite and the presence of absorbing loads for absorption of the waves of perpendicular polarization.

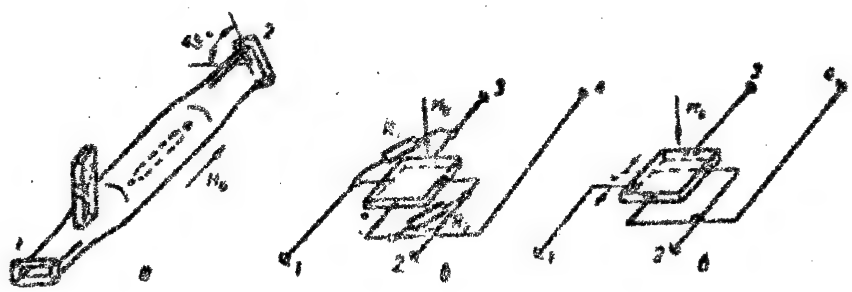

Fig.2

The addition of two matching resistances to the gyrator device based on the Hall effect converts the device into a valve, since the signals passing in back direction through the gyrator and through resistances R_1, R_2 are,

in case of their identical amplitude, mutually destroyed in consequence of phase opposition. According to the data cited in [2], such an insulator had a ratio of losses reaching 60 db in case of transmission in two opposite directions, which makes the device extremely useful in communication engineering.

A gyrator using the Hall effect can be converted to an insulator by another method, and namely by the displacement of outputs 1 - 2 and 3 - 4, as is shown in Fig. 2,c. In this way with a definite value of magnetic field, a large attenuation in the opposite direction can be obtained owing to the phase opposition of signals being formed under the Hall effect and with the voltage drop at the resistances of the pickup between equipotential planes.

If a low frequency current is passed through a control coil in a waveguide device with longitudinally magnetized ferrite, the high frequency signal at the device's output will be changed in accordance with the low frequency signal. We thus receive a convenient form of amplitude modulation. It can be demonstrated that in the device pictured schematically in Fig.3, a, at the output can be developed a signal either with ordinary amplitude modulation or with amplitude modulation without a carrier, since in principle with the turning of the output waveguide flange

in the polarization plane by 90° with respect to the input, the device allows for developing balanced modulation.

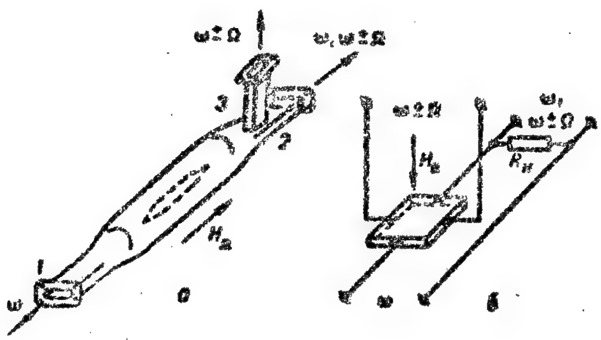

Fig.3

A similar balanced modulator based on the Hall effect is shown in Fig. 3,b. If the semiconductor material of the pickup has an appreciable effect of resistance change in the magnetic field, then the ordinary amplitude modulated signal can be received in resistance R_H connected in series with the pickup. Restoration of the carrier in the above-described balanced modulators can be accomplished either by feeding a constant component to the control winding, or correspondingly by shifting the output flange 3 to a certain angle (Fig.3,a) or by the displacement of Hall contacts 3 - 4 with a single equipotential plane (Fig. 2,c).

What is common in the devices based respectively on the Faraday or the Hall effect is that the control of their operation is realized by means of the magnetic field. It is not possible to represent and analyse the operation

of these devices by means of a planar equivalent circuit. The latter is sufficiently obvious for the case of the Faraday effect, because at the same time the turning of the polarization plane is observed. The Hall e.m.f. pick-up is a new element of electrical circuit and its equivalent circuit substitution has not been fully developed at present.

Notwithstanding many common features, the mechanisms of the Faraday effect in ferrites and the Hall effect in semiconductors are known to be substantially different. If in the former, the magnetic field interacts with the spin of the electron, then in the latter, the magnetic field acts on the movement of free carriers of charges (electrons or holes). The devices on the Faraday effect, therefore, have virtually no noises, whereas with the Hall effect noises have to be taken into account. The devices on the Hall effect can, moreover, be considered linear in wider limits of variation of input values. On the basis of the Hall effect can be designed also such devices as

detectors (linear and quadratic), amplifiers and generators [4,5]. The detectors, amplifiers and generators of the super high frequency range, using ferfites, are built on quite different principles and do not have common features with the semiconductor devices on the

†Hall effect.

We note in conclusion that the Hall effect in semiconductors (for example, in germanium) can be used in super high frequencies, in particular for turning the polarization plane in a waveguide [6] and for the construction of attenuators.

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Brief Reports

Problem of the Characteristics of a Channel with Tropospheric Dispersion

11

by R.R.Krasovskiy

The dependence of the amplitude and phase characteristics of a channel with tropospheric dispersion on frequency is of interest when the passage of continuous and pulse signals through the channel is examined.

In [1] an attempt was made to examine theoretically the structure of such characteristics. It was demonstrated that in comparison with the signal at the input, the signal at the channel output receives an additional modulation by certain random processes. The laws of the distribution of these processes were chosen in accordance with numerous experimental investigations in the field of tropospheric dispersion. The regions of the power spectrum and the phase characteristics at the channel output have been found.

In this work are cited characteristics plotted according to experimental data [2] and confirming the

the results of [1].

It is known that the amplitude and phase characteristics of a quadripole can be determined as

$$K(\omega) = \left| \frac{S_2(j\omega)}{S_1(j\omega)} \right| \text{ и } \varphi = \arg \frac{S_2(j\omega)}{S_1(j\omega)},$$

in which $S_1(j\omega)$, $S_2(j\omega)$ are the spectrums at the input and output of the channel.

To determine the unknown characteristics it is thus necessary to derive the spectrum of a signal which has passed through the channel being examined.

A square pulse with a duration of approximately 1 microsecond is taken in the capacity of such a signal[2]. Its form at the channel input and output is represented in Fig. 1.

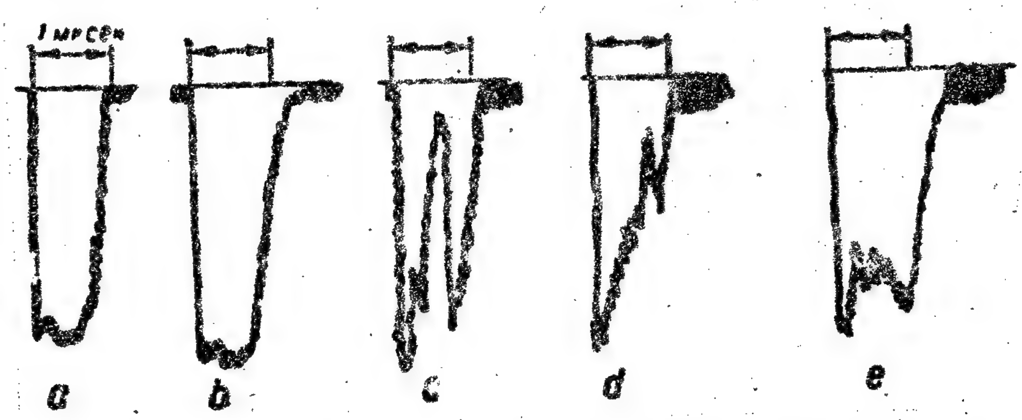

Fig. 1. Pulses a at channel input, pulses b, c, d, e at the channel output.

The pulses were subjected to spectral analysis.

All the calculations are reduced to Table 1 and

and pulse spectrums plotted according to them (Fig.2), the channel amplitude and phase characteristics (Figs 3 and 4 respectively) taking into account the transmitter and receiver channels.

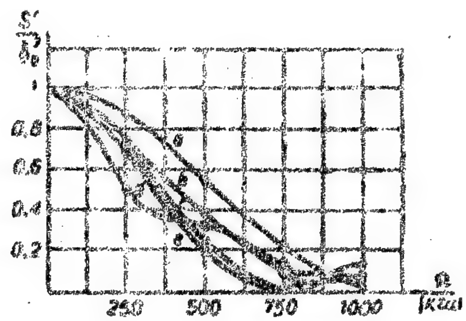

Fig.2. Pulse spectrums at the channel input and output.

a - kilocycles

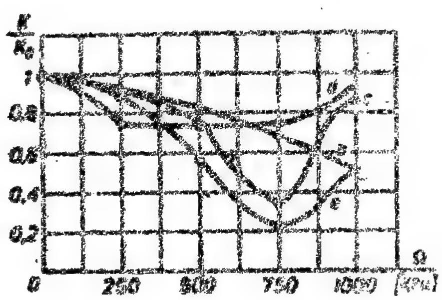

Fig.3. Amplitude-frequency characteristics of channel

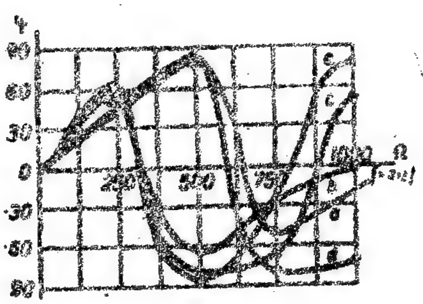

Fig.4. Phase-frequency characteristic of channel

Value of Characteristics at Various Frequencies

Table 1

pulse	a		b			c			d			e		
frequency (kc)	S'/S_0	φ_0	S'/S_0	K	$\varphi°$	S'/S_0	K	$\varphi°$	S'/S_0	K	$\varphi°$	S'/S_0	K	$\varphi°$
0	1,0	0	1,0	1,0	0	1,0	1,0	0	1,0	1,0	0	1,0	1,0	
250	0,86	41	0,74	0,92	55	0,73	0,91	50	0,48	0,74	45	·,69	0,85	64
500	0,55	82	0,40	0,85	−69	0,25	0,8	−84	0,32	0,76	81	0,20	0,58	−85
750	0,23	−58	0,11	0,70	−23	0,02	0,33	−69	0,14	0,76	−84	0,01	0,22	−20
0001	0,005	−22	0,014	0,52	−7	0,04	0,8	57	0,10	0,82	−70	0,01	0,51	08

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In the Form of Discussion

On Radio Engineering Disciplines

(Problem of Study Programs for Training Radio Engineers)

12

by Prof. M. S. Neyman, Doctor of Technical Sciences, Head of Radioreceiving Devices Faculty, Moscow Order of Lenin Aviation Institute Imeni Sergo Orzhonikidze.

Introduction

The study programs for training radio engineers lag at present considerably behind the modern state of radio-electronics. Some of the most important study disciplines which have comparatively recently developed and have already acquired or are gaining fundamental importance for the whole field of radioelectronics, are not represented or inadequately represented in the curricula. At the same time the curricula suffer from multiplicity of subject-matter and are greatly overloaded with many traditional courses which might be either consolidated or excluded entirely from the program.

The first reason for a situation like this is the circumstance that historically the radio faculties were separated from the electrical engineering faculties, which in turn, still earlier, were separated from the faculties training mechanical engineers. The frozen traces of this historical process to the present time make a substantial imprint on the composition of disciplines in the study program for training radio engineers.

The second reason is the swift development of radio electronics itself and, moreover, not only in the fields of its immediate technical applications but also in the field of its scientific foundation.

The lagging of study programs behind the modern level of radio electronics development is at present such that it can no longer be radically corrected by the simple addition of new disciplines but requires considerably more profound changes touching upon the entire curriculum as a whole. We therefore think it is timely to raise the series of questions examined below.

Discussion of questions about revision of terminology, scope and content of study program disciplines often excites big disputes and stubborn resistance, because change of the curricula upset a position historically developed and also the established specialization of faculties and

individual teachers. Moreover, since the radio faculties enter in most cases the composition of these or those polytechnical, power engineering, aviation, electrotechnical and other higher schools, one sometimes encounters, when discussing study programs, insufficient understanding of special problems of radioelectronics on the part of the general technical chairs, the chairs of other faculties and so forth, whose members form the majority of science advisory groups in the respective institutes.

Further, the transition to a new curriculum requires that serious preparatory work be done in revising subject-matter for lectures in the new courses, setting up the program, selection of teachers etc. All of this cannot, however, serve as an obstacle to raising ripe questions.

General Problems

The task of radio engineering faculties is to train radio engineers of the broad profile, who are quite familiar with all of modern radioelectronics fundamentals and capable of not only using the modern high scientific level of its development in any section of their work but also of following its further swift progress and participating actively in it.

The introduction of narrow specialties in training radio engineers is extremely undesirable for two main

reasons:

(1) as experience has shown narrow specialities cannot be observed in practice even with initial distribution and job placement of young specialists;

(2) all branches of radioelectronics continue to develop so interconnectedly and have such a profound effect on each other that the narrow specialist in a few years often finds himself inadequate even in his own narrow field.

The above statement does not exclude conducting in necessary cases a limited specialization, without touching, however, upon the study of the curriculum's basic radio engineering disciplines.

It is on the other hand necessary resolutely to protest study programs of radio engineers from attempts at their excessive enlargement for the purpose of simultaneous training of students as mechanical engineers, electrical engineers and so forth. This will inevitably inflict great damage on the fundamental radio engineering training.

Life has long since determined the ways of utilizing specialists in factories and reserach institutes of the radio engineering profile. At the present time the idea about the need of graduating specialists for the purpose of solving alone all problems of the development or

production of radio equipment, has for a long time been outmoded. Not single engineers but collective groups as a rule work on these complex problems in our scientific research institutes and at our factories. At the same time collaboration occurs between radio engineers, mechanical engineers, chemical engineers, electrical engineers, technology engineers and others, each of whom is well trained and follows the literature in his field.

Such collective works have long since became the rule at our enterprises, and only they secure the rapid and high grade solution of the complex engineering tasks at the modern, very high level of science and engineering.

In examining the study program disciplines we will not discuss the general disciplines introduced in the training of all specialties, such as the social and political disciplines, foreign language, physical training, economics and industrial organization, and also questions of the practical work of students in industry and in the industrial laboratory.

Turning to that part of the study program which is aimed at the theoretical training of radio engineers especially, it is essential to note that the volume of information corresponding even to the essential problems of modern radioelectronics alone is exceedingly large. Attempts to

force it wholly into study programs are quite hopeless. In the list of studies and in the composition of study programs must be included, therefore, only that which is fundamental for radioelectronics, and the number of courses must be reduced to a minimum, notwithstanding the objections frequently raised here.

Only such an approach can make it possible, without increasing the student load in theoretical questions, and perhaps, even with some curtailment of it, to release space for those disciplines which are as yet not studied enough or not studied at all, but have decisive importance for bringing training to ~~a~~ the modern level of radioelectronics.

We therefore have to examine not only questions of the expansion of certain disciplines and introduction of new studies, but also questions about the exclusion or combination of many old traditional disciplines, which at present overload the curricula.

Remarks on Separate Disciplines

Let us turn to an examination of the significance and content of separate branches of study in the curriculum.

The necessity of giving serious courses of mathematics and general physics, which form the basis of the majority of further theoretical and radioengineering courses, is beyond doubt. Of especially great importance is the

course of mathematics, in which inclusion is desirable of the sections:(1) introduction to analysis,(2) differential and integral calculation and ordinary differential equations, (3) analytic geometry and differential geometry,(4) vector analysis and matrix calculation, (5) differential equations in partial derivatives and integral equations (including data on special functions), (6) theory of probabilities and random processes,(7) Fourier series and integrals and certain others.

On the contrary, the giving of a separate course of theoretical mechanics for training radio engineers is optional at present and consequently, also not expedient. The essential data of this course, comparatively small in volume, can also be included in the program of the general physics course, in which must also enter the essential problems of heat transfer, the physics of semiconductors, brief exposition of piezoelectric phenomena and so forth.

The giving of the traditional separate course of chemistry can also be completely excluded. The comparatively little data on chemistry which is used in the course but does not enter the secondary school program, can be expounded in the course of radio materials.

Further,the traditional practice of giving separate courses on the theoretical bases of electrical engineering

and theoretical courses on radio engineering appears also inexpedient at the present time, since they duplicate one another and certain other courses. Instead of these two courses, it is more correct to give one major course of the theory of electromagnetic circuits, including the theory of circuits with concentrated and distributed constants and the theory of transient conditions, and also to give an expanded course of the theory of the electromagnetic field with stress on questions of super high frequency.

At the present time problems of amplification and detection, modulation and self-oscillation, are touched upon very briefly in the course on the theoretical bases of radio engineering. It is, however, more expedient to expound problems of detection and amplification of weak signals in the course on receiving-amplifying devices, problems of power amplification, modulation and harmonic self-oscillation in the course on radio transmitting devices, problems of relaxation self-oscillation in the course on pulse devices, and finally, general problems of self-oscillation, stability and discontinuity, and also problems of the noise-proof feature in two new theoretical courses which will be discussed below.

It is more expedient to replace the course on electronic and ionic devices now being given by a course

on vacuum electronics. Apart from questions of the old electronics of high frequencies (cathode, beam methods, grid control and so forth), it must also include a large section on problems of super high frequency electronics (electron guns, questions of focusing electron guns, velocity modulation, grouping of electrons, interaction of electron guns with fields and waves etc) and certain problems of ionic phenomena and devices.

This course must be mainly theoretical (for example, in the super high frequency section, in the spirit of the book "Osnovy elektroniki sverkhvysokikh chastot"(Bases of Super High Frequency Electronics) by V.N.Shevchik, Sovetskoye radio, 1959). Concrete designs of electronic and ionic devices can not be set forth in it in detail, since it is better to examine generator tubes in more detail in the course on radio-transmitting devices, receiving-amplifying tubes in the course on receiving-amplifying devices, electron beam and memory tubes in the course on pulse devices etc., in close connection with their concrete application.

Apart from the course of vacuum electronics in the study programs, it is essential to introduce a new course on solid body electronics (or more widely - quantum electronics). This course is very important at the present time already and in future its value will be still more enhanced;

it must include problems of semiconductor devices, ferrites, paramagnetic resonance and its utilization, maisers and so forth.

Further, the introduction of two separate courses -- "Theory of Signals" and "Theory of Automatic Processes" -- to the list of theoretical studies is necessary at present. These two courses must expound (applicably to radio electronics and with application in this field) that circle of problems which are at present combined under the term cybernetics.

The course on the theory of signals must embrace problems of the theory of signal circuits, including problems of the theory of information, the theory of noise-proof feature, the theory of codes, the theory of discrimination of signals and so forth. In the "Theory of Automatic Processes" course must be set forth from a unified viewpoint phenomena in systems that contain ring-like control circuits of interaction (feed back). Here belongs the exposition of problems of automatic control, stability and instability, general problems of self-oscillation, intermittent systems and so forth. These two disciplines are the most important base for the study of special radio engineering courses.

Let us now turn to examination of general engineering and special radio engineering disciplines.

Instead of the courses now given separately on the resistance of materials, machine parts and allowances and fittings, it is expedient to have one large course of technical mechanics which combines into one whole the essential problems of these courses.

Further, the giving of a separate course on the technology of metals is not expedient and the essential data from it must be introduced into the composition of the "Technology of Radio Equipment" course.

Turning to the radio materials course, it should be noted that as experience has shown the radio materials course separately given is found to be descriptive, very dry, of little interest and hard to remember for students. A great deal better results are obtained with the combined exposition of the problems of designing and calculating radio parts and the properties of materials employed in them in close connnection with the latter's technical application. It is, therefore, expedient to combine these courses into a general course on radio materials and parts.

Further, the giving of separate courses on electrical measurements, electrical machines, electric feed of radio devices and so forth is not justified at present. Instead of them there should be a single course of the electro-technical devices of radio systems, in which must enter

all problems of the electric power supply of radio devices together with problems of electric measurements, and also problems of calculation of transformers, including pulse and sound frequency, chokes with magnetic cores, magnetic amplifiers and so forth.

Turning to the special radio engineering courses, the need should be stressed of preserving and enlarging somewhat the volume of the courses on radio transmitting devices, receiving amplifying devices, antenna-feeder devices and pulse devices. The course on antenna-feeder devices, which at present is given in a scope obviously inadequate for modern electronics, especially is in need of considerable enlargement. In this course the sections on waveguides and feeder systems, connected with a very wide circle of radio devices, requires the greatest enlargement of volume.

On the contrary, the course of radio measurements and the radio wave propagation course given at present can be expediently dispensed with, in our opinion.

As a matter of fact, the methods of radio technical measurements embrace and utilize almost all phenomena and almost all types of radio electronic devices. The course of radio measurements of necessity, therefore, repeats to a very considerable extent the subject matter relating to

the subjects of all other radio engineering studies, which leads to inevitable duplication. It is thus expedient to exclude this course, after having distributed the necessary data in other courses both in their lecture and laboratory parts (for instance, problems of antenna measurement to set forth in the course on antenna-feeder devices and so forth).

Further, it is also expedient to exclude as a separate branch of study, the traditional course on propagation of radio waves. It includes in itself, on the one hand, general questions of radio wave propagation which are more conveniently given in the course on the theory of the electromagnetic field, and general questions of radio wave propagation in ionized media, which naturally refer to the course of vacuum electronics.

On the other hand, the radio wave propagation course includes a number of special problems which are more properly given in the course on the theory of radio systems, where they can be closely connected with the technical calculation and use of corresponding phenomena.

On the question of the theory of radio systems course, it is necessary to dwell somewhat more in detail.

Under the theory of radio systems we imply the branch of study that gives and substantiates methods of

calculation or selection of the optimal structure of a functional circuit and parameters of elements of a radio system designed for the performance of this or that task of radio location, radio navigation, radiometric or other similar character. Besides under radio system elements are implied transmitters, antennas, receivers, devices for processing information and other devices entering a functional circuit.

The task of the theory of radio systems is the substantiation of the selection of the necessary volume of information per unit of time, the necessary system potential, optimal wave lengths, methods of coding, methods of modulation and demodulation, powers and sensitivities, directedness of antennas and polarization of waves, methods of integration of signals and so forth. At the same time, serious consideration must also be given to problems of the reliability, operational quality, accuracy, noise-proof feature, mobility, cost and so forth.

These questions have immense importance for modern radioelectronics, especially in connection with the development of systems of radio communication, radio control, radio navigation, radio location and so forth. Not only engineers engaged in designing radio systems as a whole but also the engineers who develop devices that enter into

systems as their elements come into close contact with these questions.

The theory of radio systems has not yet been fully formulated at the present time and is not given as a separate branch of study. If instead of a general course, however, separate courses on the bases of radio location, the bases of radio navigation and so forth were given, the latter will of necessity suffer from insufficient depth and community of initial viewpoint, disconnectedness and nonsystematic exposition and parallelism.

The urgent task, therefore, is the systematization of the material available here and its examination from a unified and sufficiently profound viewpoint, on the basis, in particular, of the general theory of signals (theory of information, theory of discrimination of signals etc). The introduction of a course on radio system theory into the curriculum is, in turn, a serious stimulus for acceleration of this work.

It is expedient to complete the study program of radio engineering disciplines with several small semester or even semisemester courses, the list of which can be drawn up and modified by each of the radio faculties. In these courses can be elucidated these and other new problems, important for the given higher educational institu-

tion or faculty, and also problems of narrow specialization.

List of Study Branches

Proceeding from the considerations set forth above, we arrive at the following rough list of study branches of the program for training radio engineers (with the exception of the general disciplines, listed earlier):

Serial Number	Name of Study Branch	Scope in provisional units
	Theoretical Studies	
1	Mathematics	6
2	General Physics	3
3	Theory of electromagnetic circuits	3
4	Theory of electromagnetic field	2
5	Vacuum electronics	1
6	Solid body electronics	1
7	Theory of signals	1
8	Theory of automatic processes	1
	General Engineering and Radio Engineering Branches of Study	
9	Drafting and technical drawing	1
10	Technical mechanics	2
11	Technology of radio equipment	2
12	Radio parts and materials	1
13	Electrotechnical devices of radio systems	2
14	Radiotransmitting devices	2
15	Receiving-amplifying devices	2
16	Antenna-feeder devices	2
17	Pulse devices	2
18	Theory of radio systems	2
19	Courses on specialization and new problems	3 to 4

The figures given in the column headed "Scope in provisional units" roughly indicate the relative volume of lectures, laboratory work and exercises. They can also be regarded as a rough number of examinations in the given course (with the exception of those cases when no examination is envisaged but a test, for example, in the drafting course and in some narrow specialization courses) and as roughly the number of semesters of lectures given (with the exception of the mathematics course which it is more expedient to concentrate, providing for two or three examinations in the first semesters).

Not indicated in the list given are course projects which might be additionally envisaged in certain of the courses Numbers 10,11,12, 13,14,15,16 and 17 with a total number of 4 to 5, whereupon not more than one course project each per semester.

It should be emphasized that the sequence of study branches in the list does not correspond to their most expedient sequence by semester. We cannot here engage in an examination of these questions.

We note further that it is expedient to strictly limit the volume of laboratory training exercises, since at the present time an excessive increase is observed in setting up too large a number of comparatively monotonous

laboratory assignments, performance of which overloads the students and distracts their attention from profound working up of basic questions.

Conclusion

We have had an opportunity to dwell only very briefly on each of the complex and numerous problems that arise in an attempt to examine the problem of bringing curricula into accord with the modern level of radio engineering development. In particular, perhaps, therefore, not all that was said will be understood fully and accepted as an inevitable consequence of the modern state of the scientific foundation of this field of engineering, and also the trend of its further development. Perhaps, additional discussions and precise remarks are required, which of course must derive not from subjective considerations and interests, especially in questions of the elimination from study programs of these or those traditional branches of study, questions which are always painful and delicate.

Work on the revision of the study programs is, however, undoubtedly necessary as well as the introduction of a number of serious changes which touch not only the last but also the first years of instruction and certain of which can, at first glance, seem controversial by virtue of their novel and unusual character.

The situation created at present is such that what is required is no longer additions and corrections of the curriculum but its radical revision.

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Defense of Dissertations

13

Dissertations in Candidate of Science Academic Degree Competition

Moscow Order of Lenin Aviation Institute Imeni Sergo Ordzhonikidze

Telyatnikov L.I., Investigation of Spectrums of Amplitude-modulated Oscillations with Additional Frequency or Phase Modulation Present. Science Advisor, Dr.Tech. Sciences, Prof. M.S.Neyman. Defense was held 9 March 1959. Official opponents:Prof.I.S. Gonorovskiy, Dr.Tech.Sc., Honorary Worker of Science and Technology RSFSR; Ca.Tech. Sc. Zagoryanskiy.

A general theoretical investigation was made of the spectrums of oscillations with modulation by one and the same signal in amplitude and frequency, in amplitude and phase, in amplitude, frequency and phase. The spectrums were investigated for linear and quadratic modulation characteristics with modulation by a regular signal and random processes subject to the normal law of distribution. Quantitative ratios were derived for evaluating the effect of parasitic frequency or phase modulation on the spectrum of the amplitude-modulated oscillations.

A connection was determined between the spectrum of a frequency-modulated oscillation and the spectrum of an oscillation modulated simultaneously in amplitude and frequency.

A method is proposed making it possible to calculate the modulation characteristics of a super high frequency triode self-oscillator, taking into account the flight time of electrons both for its modulation in amplitude as well as for the parasitic modulation in frequency which penetrates at the same time.

The basic quantitative correlations of the general theory of spectrums in case of mixed kinds of modulation were verified experimentally.

Lecturer V.T.Frolkin

Lvov Polytechnical Institute
(Radio engineering faculty)

Simontov I.M., Problems of Raising Selectivity of Resonance Systems. Science Advisor, Lecturer G.A.Shevtsov. Defense was held 6 March 1958. Official opponents: Dr.Tech. Sc. Prof. Yu.T.Velichko, Ca.Tech.Sc. V.P.Sigorskiy.

A new criterion of selectivity is proposed that characterizes the capacity of a system to suppress the noise spectrum. Simple but effective methods are proposed for raising the selectivity of band resonance systems.

Amplifiers are examined having combined feedback suitable for automatic control of selectivity.

Radchenko I.A., Graphoanalytical Method of Analysis and Calculation of a Detector Cascade. Science advisor Dr.Tech.Sc. Prof. Yu.T.Velichko. Defense was held 13 November 1958. Official opponents: Prof.V.V.Ogiyevskiy, Ca.Tech.Sc. L.Ya.Mizyuk.

On the basis of the general theory of quadripoles, a detailed graphoanalytic analysis was made of various detector cascades and a method for their calculation proposed. The known family of the characteristics of rectification of detectors $I = f(U_{-})$ with $U_m =$ const. was supplemented with a second family of characteristics taken with constant amplitude of the first harmonic of input current. This affords the possibility of determining accurately the input resistance of the detector both under active and under complex load.

Sakharov T.M., Graphoanalytical Method of Calculating the Frequency Characteristics of Operating Attenuation of Low Class Differential Filters. Science advisor Dr. Tech.Sc. Prof. Yu.T.Velichko. Defense was held 13 November 1958. Official opponents: Prof.V.V.Ogiyevskiy, Ca. Tech.Sc. lecturer Ye.F.Zamora.

A simple method is proposed for accurate calculation of the frequency characteristics of the operating attenuation of differential filters by means of generalized graphs.

Cherventsov V.V., Problems of the Analysis of Multivibrators in Junction-type Semiconductor Triodes. Science advisor Dr.Tech.Sc. Prof. Yu.T.Velichko. Defense was held 12 March 1959. Official opponents: Dr.Tech.Sc. Prof. G.Ye. Pukhov, Ca.Tech.Sc. lecturer G.A.Shevtsov.

A method is proposed for calculating the basic multivibrator circuits in junction-type semiconductor triodes. An analysis was made of transient conditions occurring in multivibrators. An effective method was developed for stabilization of the multivibrator frequency by means of connecting an auxiliary LC circuit.

Nagornyy L.Ya., Analysis of High Frequency Amplifying Circuits in Semiconductor Triodes. Science advisor Ca. Tech.Sc. lecturer G.A.Shevtsov. Defense was held 12 March 1959. Official opponents: Dr.Tech.Sc. Prof.Yu.T.Velichko, Ca.Tech.Sc. Ya.K.Trokhimenko.

A generalized method of junction voltages and circuit currents was used for analysis of high frequency amplifying circuits in semiconductor triodes. An investigation

of the basic circuit parameters by means of conformal transformation is proposed.

Lecturer Ye.F.Zamora.

Kiev Order of Lenin Polytechnical Institute
(Radio engineering faculty)

Lizhdvoy K.Ya., Experimental Investigation of of a Generator of a Nonretarded Revertive Wave with Transeverse Interaction. Science advisor Prof. S.I. Tetel'baum, Dr.Tech.Sc., Corresponding Member of the Academy of Sciences Ukraine SSR. Defense was held 20 April 1959. Cfficial opponents: Prof.V.V.Ogiyevskiy, Ca.Tech.Sc. Z.I.Taranenko.

The findings are set forth of an investigation of a generator in which the electron stream passes through crossed permanent electrical and magnetic fields and interacts with a nonretarded electromagnetic wave. The generator gives continuous reconstruction of wave length for 8 to 18 cm with output power of the order of 1 watt.

The dependence of the generator wave length on the space charge magnitude was experimentally investigated. The problem was examined of transverse expansion of the electron beam by space charge forces and a formula was developed for calculating the necessary compensating forces.

The findings of the study were set forth in the

Journal "Radiotekhnika i elektronika", 1959, 3, 1, 120; 1959, 3, 2, 212.

Chzhan Tsun'-chzhin, An Investigation of the Requirements on Frequency-phase Characteristics of a Communication Channel in a System of Optimal Amplitude-phase Modulation. Science advisors: Prof. S.I.Titel'baum, Dr.Tech.Sc., Corresponding Member of the Academy of Sciences, Ukraine SSR; and Ca.Tech.Sc. L.V.Kasatkin. The defense was held 22 June 1959. Official opponents: Prof. V.V.Ogiyevskiy, Ca.Tech.Sc. I.V.Akslovskiy.

The method of optimal amplitude-phase modulation (OAPM) proposed by Prof. S.I.Titel'baum in 1938-1939, makes it possible to realize in practice the advantages of the ordinary ~~single-~~ band transmission, to cut in half the width of spectrum of the signal studied as compared with the usual AM and to secure nondistorted reception by means of the usual receiving devices with amplitude detection.

In the dissertation work are determined permissible frequency and phase distortions in separate sections of the transmission channel, permissible distortions in circuits of functional transformations under various methods of these transformations in OAPM systems.

A new possibility is proposed for functional transformation in OAPM systems by means of a device that

accomplishes a turning by $-\pi/2$ of the phase of the frequency components of the modulating program's logarithm.

The investigation of the requirements on frequency-phase characteristics of a communication channel in an OAPM system showed the possibility of realizing the advantages of the optimal modulation method without substantial reconstruction of the transmitting centers and preservation of the stock of receiving devices in operation.

Lecturer V.P.Taranenko.

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Criticism and Bibliography

14

V.P.Sigorskiy "Metody analiza elektricheskikh skhem s mnogopolyusnymi elementami" (Method of Analysis of Electrical Circuits with Multipolar Elements), Academy of Sciences Ukraine SSR Press, Kiev, 1958, 402 pages, price 13 rubles, 50 kopeks.

Review

The booming development of radio engineering, automation, telemechanics, measurement techniques and other branches of science and technology makes demands on effective methods of analysis and synthesis of complex electrical circuits. The actuality of the problem is confirmed by the voluminous literature on the theory of electrical circuits, which has appeared in recent decades.

The book of V.P.Sigorskiy is devoted to a study of the methods of analysis of electrical circuits with multipolar elements. To such circuits belong all the diversity of circuits encountered in modern radio engineering, which is what determines the exceptional importance of the theme. The book consists of three parts. In the first part is

set forth the theory of circuits with multipolar elements, worked out by the author; in the second, its application, and in the third part, the author's methods are compared with other existing methods.

Matrix algebra is widely used in the book. The author points out the convenience of matrix calculation when working on computers.

The <u>first part</u> of the book is the theoretical base of the linear theory of circuits. The history of the problem is briefly expounded in the introduction. One can agree with the point that "the theory of linear electrical circuits is gradually going beyond the framework of a section of theoretical electrical engineering and is acquiring the character of an independent branch." (Page 7)

The theory of circuits is constructed on the basis of generalization of circuit and nodal equations in the case when multipolar elements enter the circuit also along with passive and active two-terminal networks. Besides, the duality of the nodular and circuit equations is successfully taken into account and instead of two dual systems of equations, their generalized form is used.

Examined in detail are problems connected with the selection of a system of reading variables (system

of coordinates), in the capacity of which any system of circuits, any system of nodal pairs serves. The practical value of the canonical systems of coordinates, when the form of equations of the circuit is simplified to the limit, is emphasized here. The problem of transition from one system of coordinates to another is solved by means of linear transformations. Other transformations are also examined - reduction and expansion of the coordinate system, and also the isolation of some kind of group of coordinates.

An expanded canonical system of coordinates, in which each pole or external circuit of the multiterminal network is put in an equal position, was adopted for the description of multipolar elements. This allows for using the matrix of a multipolar element as its generalized parameter, which is found extremely convenient in determining the matrix-vector parameters of a complex circuit. The latter problem is solved in the general case by means of a matrix, the author developed, of connections, which combines in itself the operations of addition and transformation previously examined. The matrix of the system is determined through reducing the matrix parameters of the elements to a selected system of coordinates and their subsequent addition. The rule of recording the circuit

matrix in canonical systems of coordinates is found especially simple, which is of decisive importance in application to electrical circuits.

Typical for the concluding stage of the analysis, determination of values that characterize the circuit, is the reduction of the process of solving the system of equations to operations over matrix-vector parameters. In addition to well known methods, the generalized Gauss algorithm is examined here, correlations are developed for the case when the circuit equations are written in complex form. A large class of circuits is reduced to the transfer quadripole. In the book are developed correlations that characterize quadripoles (transmission factors of current and voltage, input and output resistances and so forth), which are expressed through the determinant and algebraic complements of the circuit matrix. A table convenient for use is quoted.

The important question of electrical circuit theory on variation of circuit parameters is examined in the conclusion of the first part. After expounding the Polivanov theorem of variation, the author cites two generalized theorems of variation he developed that are good for calculation of changes in values characterizing the circuit with variation of element parameters. In the

proof of the second generalized theorem of variation use is made of the author's theorem about the expansion of the determinant of the sum of two matrices, for which a series of other interesting applications in electrical engineering calculations is also indicated.

In the second part is set forth the application of the theory of circuits with multipolar elements to the analysis of electrical circuits. Here circuits are examined in detail with a large number of well selected examples, circuits formed of two-terminal networks, circuits with mutual inductances and especially circuits with electronic tubes and semiconductor triodes. Canonical systems of coordinates are used for the latter, owing to which the process of analysis is greatly simplified. It can be stated that the author's methods have passed the matriculation examination in application to electronic circuits.

The third part is a critical survey of other methods. The author develops existing methods in two groups: (1) methods based on equivalent circuits and (2) methods based on the splitting of a complex circuit into subcircuits. In the first group is examined the method of equivalent circuits, the method of convolution, the method of orienting graphs, and also the use of ideal multiterminal networks (the ideal power transformer, gyrator). In the other group-

is examined the method of the multiterminal network and the quadripole, and also the method of subcircuits. The author shows the advantages of the generalized methods he has developed over other methods and also indicates clearly the rational field for application of each of the methods examined.

The matrix-tensor method of Kron, which for more than two decades has been acclaimed the highest achievement of modern electrical engineering, is subjected to profound analysis in the book. The author exposed the defects and errors in the theoretical substantiation of the method, clarified the essence of the "elementary circuit" developed by Kron and traced those difficulties which arise when the method is used for analysis of electrical circuits. The perfectly correct conclusion that "application of the Kron method does not give any kind of advantage in the practice of electrical circuit analysis, even in comparison with elementary methods," is given in the book.

The bibliography has 323 titles, including 178 Russian sources. Here we find all that is most essential relating to the subject matter. The bibliographical fullness and the considerable number of references make it possible to consider the book being reviewed as a work which summarizes a whole stage in the development of the linear theory

of electrical circuits.

The book is carefully styled, written distinctly and clearly and well constructed in a methodical sense.

In the work are a number of errors and misprints. The reiterating misprints in the examples on pages 97 and 98 and also 103 and 104 are especially unpleasant. In the formulas (216), (218) and (219) the upper indices a and b should change places and, moreover, the second sign of the sum is ommitted in formulas (218) and (219). The multiplier q_i has been ommitted in formula (222). In Fig. 124,b, the direction of current I_1 should be changed to the reverse and the sign changed before I_2 in the third equation on page 282. There are a number of misprints in the intermediate transformations which although they do not affect the final result, make reading difficult.

On the whole the monograph reviewed is a valuable contribution to the theory of electrical circuits. The methods developed by the author enlarge considerably the possibilities of analysis of electrical circuits, especially circuits with electronic tubes and semiconductor triodes. The book contains many valuable ideas which can serve as the basis of further investigations in this field.

Although the book in character is not a textbook, many of the findings, especially the practical methods of

analysis of electonic circuits, merit being communicated to students of senior courses and graduate students of electrical and radio engineering specialties. Undoubtedly the book will prove interesting and useful to research associates, teachers and well trained engineers.

Received by the editors 16 July 1959.

Prof. Doctor of Tech.Scien. Yu.T.Velichko.

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Foreign Information

15

Work in Training Methods and Scientific Research at the Eastern Chinese Pedagogical University

(Physics Faculty)

The Eastern Chinese Pedagogical University was organized in 1951 from several higher schools of Shanghai for the purpose of training secondary school teachers. In the physics faculty then were only 7 teachers and 25 students. Now upwards of 5000 students, including more than 700 in the physics faculty, are being trained in the university's ten faculties. Soviet specialists who worked in our university gave us substantial assistance.

A course of radio engineering in conjunction with the electrical engineering course was introduced in the faculty in 1952. The book "Course of Electrical and Radio Engineering" by Prof. N.N.Malov, of Moscow Teachers College, served as the textbook. Later the number of lecture hours in the radio engineering course was increased, school appliances and materials were created directly in the faculty and the radio engineering course became an independent branch of study.

In the new study program 127 hours have been allotted to the lectures of the radio engineering course, which exceeds the 1955 study program by 50 per cent.

Such a substantial increase in the radio engineering course hours was caused by the circumstance that in practice we had become convinced of the great importance radio engineering has in the development of modern science and engineering, which is especially important for us now when our country has adopted the course of manifold development of scientific research work at the time of the big leap in 1958.

Such branches of study as television, pulse technics, technology and electrotechnics of super high frequencies, semiconductor devices have been introduced in our new study program. The sections on measurement devices, and also computers and circuits, have also been expanded.

In the laboratory studies in physics, work in electronics has been separately organized, new laboratory studies are being conducted in microwaves, pulse technices and so forth.

Owing to participation in NIR (apparently scientific research work) the students acquire sufficiently practical skills, which made it possible for us to omit including in the schedule training exercises of the course in applied

radio engineering. Apart from the compulsory program of laboratory studies, the students must perform independently one work on a chosen theme.

In the faculty a series of training method measures is put through, among which the following should be stressed:

(a) the collective reading of courses and conducting consultations by several teachers (each teacher gives separate sections of the course and prepares lectures jointly with other teachers).

(b) The organization of excursions making it possible to combine training with production, theory with practice. In particular, excursions were organized to the radio broadcasting system, the radio center of long-distance communication, a radio factory that produces receiver sets, a radio parts factory. Exhibits of electronic devices and radio parts were organized by teachers and students in the faculty.

(c) The course lectures are accompanied by the demonstration of visual aids(radio devices, radio parts and so forth).

(d) The wide introduction of student production practice. After completing the course all the students work during a month at a radio factory. Our experience shows

that production practice is the best method of overcoming the gap between theory and practice.

From September through December 1958 all students of course one went through production practice at a factory and now by their own hands are making many complex devices produced by the factory.

(e) Obligatory participation of students in scientific research work for enhancing knowledge and gaining practical skills.

The primary direction of our scientific-research studies is the technics of microwaves. At the present time we are conducting the following studies:

(a) making an experimental linear accelerator for $4 \cdot 10^6$ electron volts, the start of which is planned for the end of 1959.

(b) making a microwave device for measurement of distance.

(c) a testing unit has been created with a round 8 mm waveguide 200 m long and certain essential measuring devices for studying the problem of investigating the propagation of H_{01} wave at long distances in a waveguide; the unit with the round 8 mm waveguide 200 m long has already been created.

(d) the design of electronic tubes for microwaves,

in particular of the lighthouse type and klystrons.

(e) an experimental investigation in radiospectroscopy in microwaves is planned.

(f) object lessons in television and remote control models of aircraft, etc, are being made.

The principle for selection of scientific research themes is based on combination of production with study. In the organization of research studies the work of students is coordinated with the work of teachers. In each scientific research theme a group is organized, in which teachers, students and technical personnel participate. The scientific research work of our school is conducted in collaboration with the Shanghai Institute of Electronics, Academy of Sciences of the Chinese Peoples Republic, with designing and scientific research institutes, factories and so forth. Soviet specialists gave us great assistance in the conduct of scientific research work. Thus, Yu.K.Kaznacheyev delivered a report to us on "Distant Propagation of H_{01} Type Wave in a Waveguide," N.T.Bova, lecturer of the Kiev Polytechnical Institute, gave a report on "Ways of Developing the Technics of Super High Frequencies","Super High Frequency Antennas"," Measurement of Low Powers" and so forth.

Both in training methods and in scientific research work we receive great help from our true and reliable

friend - the Soviet Union. We use a number of textbooks translated from the Russian language. In the laboratories of the university there are many devices received from our Soviet friends. We know that the Soviet Union is a worthy example for us, from whom we must learn and, following in the path broken by USSR, we see our bright and splendid future. The achievements of the Soviet Union in the field of science and technology makes us sincerely rejoice and from the whole heart we desire our soviet friends still more successes in the struggle for our common cause of communism.

Chen Ye-kue, Head of the Electronics Chair of the Physics Faculty, Eastern Chinese Pedagogical University.

25 March 1959, city of Shanghai.

Chronicle # 16

All-Union Science Session Dedicated to the Centennial of the Birth of A.S.Popov, Inventor of the Radio

An All-Union Science Session dedicated to the centennial of the birth of A.S.Popov, inventor of the radio, was held from June 8 to 13 in the assembly hall of the Moscow State University and the Central House of the Soviet Army. It was convened by the Scientific-Technical Society of Radio Engineering and Electric Communications imeni A.S.Popov, the Organizational Committee for Conducting the Centennial of A.S.Popov's Birth, the State Committee on Radioelectronics of the Council of Ministers USSR, the Ministry of Communications USSR, the Ministry of Culture USSR, the All-Union Council on Radio Physics and Radio Engineering of the Academy of Sciences USSR.

Upwards of 2000 specialists participated in the session's transactions. They included representatives of higher educational institutions, scientific research establishments and industrial enterprises, and also the

representatives of scientific technical societies of Hungary, German Democratic Republic, Poland, U.S.A., Czechoslovakia, China, France, England and Rumania.

The chairman of the central administration of the Scientific Technical Society of Radio Engineering and Electric Communications imeni A.S.Popov, a corresponding member of the Academy of Sciences USSR, V.I.Siforov, opened the session.

At the first plenary meeting on 8 June the gold medals imeni A.S.Popov awarded by decision of the Presidium of the Academy of Sciences USSR were ceremoniously handed to Dr.Louis Essen (England) for work in the creation and application of the atomic standard of frequency and to Doctor of Physical-Mathematical Sciences S.M.Rytov (USSR) for a series of studies in the field of statistical physics.

Academician A.N.Nesmeyanov, president of the Academy of Sciences USSR, warmly greeted the winners of the A.S.Popov gold medals and handed them the awards and the associated diplomas.

At this same session reports were made by Acad. A.N.Shchukin on the effect fluctuation noises have on the accuracy of determination of coordinates by radiotechnical methods and by Acad. V.V.Parin on the application

of radioelectronics in medicine and biology.

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The session's work proceeded in 15 sections in which more than 300 reports were made about the findings of scientific research and practical studies in the field of radio engineering, electronics and electric communications, carried out in scientific research institutions, industrial enterprises and higher educational institutions of Leningrad, Moscow, Gorky, Kiev, Taganrog, Tomsk, Novosibirsk, Odessa, Rostov, Kuybyshev and many other cities of the country.

At the theory of information section 32 reports and papers were communicated. Of considerable interest is the findings of the study of V.I.Siforov and L.F. Borodin on the coding of telegrams with uniform correcting codes. Worthy of note is the great scientific and practical value of the reported work which consisted in the creation of a method of determining the economic effectiveness of coded communication and the creation of regular methods of designing correcting codes, applicable to the specific conditions of departmental communication. Of practical and theoretical interest are the materials of Yu.S.Lezin's report on threshold signals during incoherent accumulation with exponential weighted

function.

The interesting and new method of analysis of spectrums, reported by V.Ye.Murav'yev, should also be noted. Set forth in N.L.Teplov's report was a general method of analysis of the noiseproof feature of systems with discrete signals during coherent and incoherent reception and general principles were formulated for the design of communication systems to realize maximal noiseproof feature. The report of B.N.Mityashev was interesting and examined the question of the noiseproof feature of one method of determining the transient position of pulses. The problem of using light as a channel of information transmission was the topic of the report of G.I.Rukman and G.M.Khaplanov, a subject of scientific and practical importance. Of great significance for practice are the findings of B.S.Tsybakov during investigation of the problem of the carrying capacity of multibeam channels of communication. Also of interest is the report of L.F.Borodin devoted to the rate of transmitting communications in symmetrical channels. The reporter's findings have scientific and practical importance. Note should be taken of the novelty in the problem formulation, the usefulness of the findings in a little explored field of the theory of systems, based on the use of step-

by-step analysis in problems, the detection of the signal in multichannel systems, expounded in the report of A.E.Basharinov, B.S.Fleyshman and G.S.Tyslyatskiy. The solution of problems of coding speech has great theoretical and practical importance. Work on this problem is being done in the Soviet Union and abroad. New methods of coding that have great promise for application, were examined in the interesting report of A.M.Polykovskiy.

At the general radio engineering section 26 reports were made. Most lively was the discussion of the reports: Ye.Ye.Zhabotinskiy and Yu.L.Sverdlov - on multicascade frequency multipliers; A.M.Polykovskiy - on new means of synchronic modulation and synchronic detection; G.M.Utkin -on polyharmonic conditions in self-oscillators; M.Ye. Shteynshleyger and G.S.Misezhnikov - on two and multiresonator quantum amplifiers; V.F.Nesteruk - about integral method of detecting the pulse signal on a noise background; D.M.Vakman - on calculating transient conditions in frequency modulation; A.L.Fel'dshteyn and L.R. Yavich - on the experience and prospects of cataloging of certain elements of the super high frequency channel.

At the super high frequency ferrite devices section 16 reports were made. The problems discussed at the section meetings embraced two trends, the first of which

was connected with the problem of creating low-noise devices using ferrites. The new results in this part are: clarification of a series of problems connected with the theories and ways of realizing parametric ferrite amplifiers of the electromagnetic type (report of A.L.Mikaelyan and N.Z.Shvartz) and mixers using nonlinear phenomena in ferrites (report of A.L.Mikaelyan and V.Ya. Anton'yants), elaboration of problems concerning the theory of the most promising ferrite amplifiers of the magnetostatic type (report of A.A.Pistol'kors and Syuy Yan'-shen' and the report of Ya.A.Monosov), elaboration of the theory of shock electromagnetic waves, generated by the nonlinear properties of the ferrite medium (report of A.V.Gaponov, L.A.Ostrovskiy and G.I.Freydman). The second trend concerned linear waveguide ferrite devices. Of most interest in this part is the theory of phenomena in the limit waveguides with ferrites, indicating the possibility of creating a new type valve (report of A.L. Mikaelyan and A.K.Stolyarov). Also of interest is the elaboration of a series of questions concerning the theory and calculation of resonance type valves (reports of A. K.Stolyarov, N.M.Kovtun and M.V.Vambergskiy).

The main trend in the work of the electronics section was the problems connected with the super high fre-

quency electronic devices. A portion of the reports heard at the section was devoted to the investigation of super high frequency devices that are already comparatively well known. In other theoretical reports were discussed problems connected with the creation of devices based on new principles (interaction of electrons with nonretarded waves, parametric amplification, use of gas discharge and others).

The report of I.M.Bleyvas, I.I.Galitska, I.M.Kal'vin and Ya.I.Mestechkin aroused great interest. The investigation which the authors of the report made in the electronic phenomena in the space of the interaction of super high frequency devices by means of an automatic device for plotting trajectories of charged particles has great theoretical and practical importance. The experience in operating the automatic device showed that it is a valuable instrument for the investigation and development of super high frequency devices. Also of considerable interest is the report of V.P.Shestopalov on the dispersion properties and spatial resonance of a helical waveguide placed in a magnetic-dielectrical medium. The investigations made by A.I.Tereshchenko and V.A.Korobkin are also actual. In them practical results were obtained in the creation of new more effective forms of resonator magnetic sound recorders. ~~Also noteworthy in theoretical~~

interest is the report of M.I.Kuznetsov, M.I.Berbasov and V.Ye.Nechayev, in which were set forth the findings of investigations directed to clarification of the physics of fluctuation processes in a magnetic sound recorder.

The report of I.M.Bleyvas, Ya.I.Mestechkin and V.B.Khomich described the results in developing a small dimensional trajectory for solving equations of the travel of charged particles in electronic and magnetic fields. Considering the great scientific and practical value of creating such a universal instrument for radio electronics and physics of charged particles, measures should be adopted for the urgent set up of the serial production of the developed device. Of practical interest for many fields of radio electronics is the report of A.M.Kharchenko, G.V.Bykhovska, M.I.Yelinson and D.V. Zernov in which electronic contact tubes and certain possible circuits of their application were examined.

The report of G.N.Rapoport was devoted to the problem of exciting a waveguide by an electron beam with periodically varying trajectories. The question examined in the report is extremely actual for new trends in the development of super high frequency electronic devices.

A.I.Chikin's paper expounded material having interest in connection with the need to include research

in lowering low frequency noises in the plans of new developments of electrovacuum devices.

The optical-radiophysical methods being developed in recent years, as one of the trends of quantum radio engineering, are of great scientific and technical interest. Especially promising is the development of these methods for solving problems that arise in mastering new shorter-wave bands of the electromagnetic spectrum of waves. These questions were reviewed in the report of G.I.Rukman and G.M.Khaplanov.

The report of V.A.Afanas'yev "Prospects of Lowering the Noise Factor of Super High Frequency Electronic Devices" aroused great attention, because the solution of this problem is extremely actual at present. The method proposed in G.A.Zeytlenk's report for calculation of induced current is a signficant contribution to the theory of the interaction of the electrical field and the electron stream in a planar gap without space charge.

The report of A.V.Gaponov "Interaction of Electromagnetic Waves with a Non-straightline Electron Stream" should be noted. The theoretical analysis reported by the author is of great interest.

At the <u>television section</u> 32 reports devoted to different problems of television broadcasting technology

were read and discussed. The greatest portion related to elucidation of the results in developing new apparatus and methods used in color television; reports relating to it were: V.I.Baletov "Color Television Apparatus for Moscow Telecenter", V.A.Buldakov "Color Television Studio Chamber", V.L.Kreytsev "Transmission of Two Independent Television Programs in a Common Channel of Communication", L.N.Shvernik and D.D.Sudarskiy "Projection Devices of Color Television" and a number of others. A large group of reports at the section was formed of papers relating to development of new methods of varied kind of measurements in the television channel and apparatus for making these measurements. Worthy of note are the reports: M.I.Krivosheyev "Measurement of Fluctuation Noises in Television", N.G.Deryugin "Device for Checking the Linearity of the Television Channel", V.I.Yeremin and O.Ye. Yevnevich-Chekan "Generator of Pulses of the Quadratic Sinus Type" and others.

Great interest among session participants was aroused by the report of V.G.Koltsov and A.S.Angelov "Television Set on Semiconductor Devices", in which all cascades are developed in transistors. The sole vacuum element is a kinescope of the 43LK6B type. The power consumed by the television set is roughly 15 watts with

feed voltage of 12 volts. The picture dimension is 360 x 270 mm.

At the radio wave propagation section were given 26 reports devoted to a number of important trends in modern investigations of radio wave propagation. To the first group of problems belongs the theoretical and experimental investigation of tropospheric propagation. The phenomena of dispersion, diffraction, turbulence, loss of antenna amplification and spaced reception in long-distance tropospheric propagation of ultrashort waves were examined in a series of reports. Many of the research findings will be of practical use in the designing and operation of ultrashort wave lines of communication. The second set of problems embraces the theoretical and experimental study of nonuniformities in the ionosphere and their effects on wave propagation. The study of the fine structure of the ionosphere, made in the reports read, has practical importance for the operation of modern ionospheric lines of communication. In a third group of problems enter multichannel radio communication and long-distance (and super long-distance) reception of television signals.

At the section was given the report of W.S.Halsted (USA) devoted to modern complex systems of combined

long distance communication with use of tropospheric propagation of ultrashort waves. The reporter dwelt both on existing lines of multichannel radio and television communication as well as on future prospects of the development of radio communication between the U.S.A. and Europe.

The radio receiving devices section heard eight reports which were devoted to:(a) synthesis and calculation of amplifying systems;(2) methods of radio reception, circuits and parameters of radio receivers. The paper of V.I.Shasherin aroused great interest. It brought clarity to the problem of the conditions producing the optimal characteristics of multicascade wide band amplifiers. Very valuable and original material was set forth in the report of G.I.Levitan and O.I.Vostyakov on filters with artificial compensation of losses and electrical regulation of pass bands. In a number of other reports information was given about a super high frequency radio receiver with very narrow pass band and singular solution of the problem of automatic tuning (report of A.G.Golubtsov, L.T.Remizov, L.S.Tyufyakin); a new method was set forth for radio communication with automatic suppression of pulse noises (report of Yu.N.Babanov); a method of calculating the detector head of super high

frequency receivers was presented (report of V.V.Ragozin); very valuable data on the selectivity of ultrashort wave receivers, for developing broadcast receivers and for designing broadcast networks was communicated (report of V.I.Savitskiy).

At the electronic computer technology section 25 reports were given. Questions of using semiconductors in computer devices were touched upon in a number of reports. A portion of the papers was devoted to the application of ferrite elements in computer devices and ~~their~~ reliability. In other reports, the prospects of high speed circuits in magnetic elements were examined. Reports were heard devoted to new developments of memory devices in magnetic elements and special electron-beam tubes.

Reports heard with great interest were: V.I.Gevorkyan "Dynamic Trigger in Semiconductor Triode", A.Yu.Gordonov, Ye.B.Gol'dshtik, Ye.I.Zorkov, V.A.Kalikhman and G.V.Katolikov "Special Elements of Digital Computers in Semiconductor Devices", L.N.Patrikeyev, T.M.Agakhanyan and N.S.Belov and others "Set of Semiconductor Elements and Units of a Digital Computer". Described in the report of N.V.Korol'kov and V.S.Gavrilov were magnetic elements of the choke type, operating in frequency cycles of a hysteresis loop, which create new possibilities for increasing

the high speed and reducing the power consumption in digital computers.

The theoretical and practical interest should be noted of A.A.Genis's report "On Calculating Circuits in Thyratrons without Filaments". The prospects of using single-cycle ferrite diode circuits with low frequencies of cycle pulses were indicated and interesting examples of the indicated circuits given in the report of V.A. Ramchits.

The <u>transmitting devices section</u> heard and discussed nine reports. Of great interest was the report of M.S.Neyman "On Certain Basic Questions of the Development of Powerful Radio Transmitters", in which interesting prognoses were made of possible trends in the development of powerful radio transmitting devices.

The findings set forth in the paper of V.V.Malanov and M.P.Polov, "Theoretical and Experimental Development of a Pulse Amplifier of Sound Oscillations with 1200 Watt Power and Industrial Efficiency 50", can have great significance for raising the quality of powerful modulator devices of radio transmitters. A method of substantial raising of the technical indices of single-band radio transmitters was proposed by V.I.Rassadin. A method of calculating cascades of radio transmitters with

auto-anode modulation, that is more convenient and adapted for purposes of analysis and designing, was set forth in the report of Yu.V.Bogoslovskiy.

The theory developed in the paper of Ye.P.Korchagina,"On the Stability of Stationary Conditions of a Generator with Circuit between Anode and Grid", makes it possible to explain a number of phenomena which are observed in practice and have not previously found a satisfactory explanation. The considerable interest should be noted in the report of S.I.Yevtyanov,"Two-cycle Frequency Dividers", in which was proposed a new class of circuits for frequency division, and the findings of their theoretical and experimental investigation were also cited.

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At the concluding plenary meeting, corresponding member of the Academy of Sciences USSR V.I.Siforov spoke, devoting his address to the theory of radio communication channels with random variable parameters.

Corresponding member of the Academy of Sciences USSR A.A.Pistol'kors reported on the problem of the synthesis of antennas.

Doctor of technical sciences A.L.Mikayelyan examined problems of the nonlinear theory of a ferrite generator which makes it possible to not only establish the

conditions of the excitation of parametric oscillations but also to calculate the amplitude of the oscillations in the steady-state conditions.

In the report of Doctor of physicomathematical sciences E.I.Adirovich were examined the reactive properties of transistors that determine the junction and frequency-phase dependencies which are defined by the relaxation processes taking place in the p-n junctions and in the areas of quasineutrality.

The representatives of the scientific technical public of foreign lands delivered greetings to the conference, stressing the importance of the session held in the cause of strengthening and expanding the scientific technical ties of Soviet scientists and engineers with the specialists of foreign lands.

Engineer L.G.Stolyarov

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To the Sixtieth Birthday of Prof. A. M. Kugushev

The community of the Higher Technical College imeni Bauman in Moscow jointly with representatives of industrial organizations and the All-Union Scientific Technical Society of Radio Engineering and Electric Communications imeni A.S.Popov on 19 June 1959 observed the sixtieth birthday of Aleksander Mikhaylovich Kugushev, Doctor of Technical Sciences, Professor of Moscow Higher Technical College.

Professor A.M.Kugushev is one of the oldest workers of Soviet radio electronics, having begun his working career in the Nizhegorodskaya Radio Laboratory imeni V.I.Lenin. Being associated with the laboratory since 1919, as the military representative of the Workers' and Peasants' Red Fleet, he joined its staff after demobilization in 1922 and took an active part in the development of standard low power radiotelephone transmitters, large sources of power supply and the powerful radiotelephone station in the city of Moscow (the radio station imeni Komintern). Working at the Nizhegorodskaya laboratory under the guidance of M.A.Bonch-Bruyevich, A.M.Kugu--

shev began a cycle of investigations of powerful transmitters of ultrashort waves, which he later proposed in Leningrad and then in Moscow. In consequence of these studies, the effect of reactive circuit elements on the operation of a super high frequency self-oscillator was clarified for the first time and the production of the large powers of super high frequency oscillations in demountable tubes was practically mastered. These results were utilized in radio location technique and in the hardening of large steel work-pieces by super high frequency oscillations. During the forty-year period of his career in science, Prof. A.M. Kugushev has written about a hundred published works, the major part of which relate to the technology of super high frequencies. For many years the director of the transmitting devices laboratory of a scientific research institute and the radio engineering faculty head at the Higher Technical College imeni Bauman, A.M. Kugushev also participates largely in public life. For several years already he is the chairman of the Moscow Oblast administration of the All-Union Scientific Technical Society of Radio Engineering and Electric Communications imeni A.S. Popov, an active member and chairman of one of the sections of the All-Union Society for Dissemination of Political and Scientific

Knowledge, a member of several science councils.

The Government of USSR has repeatedly acknowledged the services of Professor Aleksander Mikhaylovich Kugushev in the development of Soviet radio electronics, having awarded him a number of orders and medals.

Lecturer L.A.Lyubimov.

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